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RECORDING MOTOR-VEHICLE SPEED AND PLACEMENT

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D. M. BEACH, *Editor*

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The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

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NEW TECHNIQUES IN TRAFFIC BEHAVIOR STUDIES

BY THE DIVISIONS OF TESTS AND HIGHWAY TRANSPORT, PUBLIC ROADS ADMINISTRATION

Reported by E. H. HOLMES, Highway Engineer-Economist, and S. E. REYMER, Assistant Research Engineer

SIGNIFICANT ADVANCES in the technique of studying traffic movement have been made during the past year. New devices have made possible the collection of data needed in studies of highway capacity simply, accurately, and far more cheaply than has heretofore been possible. These devices also have opened entirely new fields of study of the requirements for safe operation of vehicles on our highways.

In 1934, the Public Roads Administration began studies of highway capacity. In these studies, attempts to determine a reasonable or working capacity from theoretical computations were discarded in favor of determinations based upon actual driving practices on representative highways, and an entirely new conception of highway capacity was advanced. This conception differed basically from that of previous approaches to the subject in that the index of highway congestion was based upon the opportunity for the individual driver to travel at his desired speed rather than upon the average speed of all vehicles. Although increasing traffic volumes have been found to reduce the average speed of traffic to some degree, this index, as compared to indexes of the movements of individual vehicles, is relatively insensitive and shows no marked break at which it may be said congestion begins.

Average speeds of traffic may be determined very accurately by an analysis of only a sample of the traffic. Determination of the freedom of movement of individual drivers, however, requires a knowledge of the speed of each vehicle in the traffic stream and its relation to the speed and position of vehicles ahead and behind. Accordingly, methods had to be developed for determining the speeds of all vehicles so that they could be accurately related to one another. This method was described in the February 1939 issue of PUBLIC ROADS.

Studies were conducted under this procedure by the Public Roads Administration in Massachusetts and New York in 1934 and 1935, and in Illinois in 1937 in cooperation with the highway planning survey in that State. However, the scope of the data that could be collected was limited by a variety of factors, and it was practically impossible to observe traffic under a sufficient number of conditions to provide conclusive results.

IMPROVEMENT OF FIELD EQUIPMENT NECESSARY TO OBTAIN ADDITIONAL DATA

The large field force needed was expensive and inconvenient to transport. The necessity of reading license numbers practically confined the work to daylight hours, not only eliminating the study of darkness as a factor in traffic behavior but also preventing observation of some of the heaviest traffic densities. Rain and cold were serious handicaps. The minimum length of section of 0.2 mile precluded observations under physical conditions prevailing for less than that distance. Finally, the office analysis was a tedious and expensive process.

The advantages of the method far outweighed the disadvantages, however. By no previously known method was it possible to obtain the complete information required for these detailed analyses, and the value of the results in showing driver practices under various traffic conditions has been clearly demonstrated. But with the advent of the highway planning surveys and the completion of the basic traffic volume studies, the necessity for more complete knowledge of the factors determining highway capacity became increasingly evident. Traffic density figures for the more heavily traveled roads are of little value unless they can be evaluated in terms of highway capacity. Demand for information similar to that collected in these earlier studies showed that improvement in the field technique was imperative, not to improve the quality of the data, but because more data were needed, added conditions had to be observed, and the results had to be analyzed more quickly.

The requirements of a new method were definitely established on the basis of the earlier experience. The major requirements were as follows:

1. The speeds of all vehicles must be measured.
2. Each speed measurement must be recorded.
3. The time spacings between vehicles must be determined and recorded.
4. The process of determining and recording these items for each vehicle must be completed in less than 1 second.
5. The records must permit segregation of data by traffic lanes, and the direction of travel of each vehicle must be indicated.
6. All measurements and recordings must be entirely automatic, because of the anticipated widespread application of the method.
7. Speeds must be measured with an error of less than 5 percent within the normal range of vehicle speeds.

An extensive survey of existing methods of speed detection revealed that none of the available devices would satisfy all of the requirements and, accordingly, an entirely new mechanical-electrical device was developed. In the conception of this device, the element of recording was perhaps of somewhat greater importance than that of speed determination, for various electronic or other devices would suffice to determine speed reasonably well. Since the Public Roads Administration had obtained satisfactory results with the graphic time recorder in other studies, the new method was developed with that particular type of recording device as its basic element.

The speedmeter is fundamentally a time-measuring instrument consisting of a detecting unit, a timing unit, and a recording unit. The speed of a vehicle is obtained by determining the time it takes in traversing a known distance. The detecting unit functions as two switches placed on the road a definite distance apart. A vehicle in passing over first one and then the other of the two switches starts and stops the timing unit, whereupon the recording unit records the speed of the vehicle. Usually the time required for the entire operation is less than 1 second.

Of the several types of detecting units that may be used, the simplest is of the direct contact type in which each switch consists of a pair of continuous metallic tapes laid across the highway and separated at intervals by some flexible insulating material such as rubber. Detection by lanes may be accomplished by segmenting one of the tapes and using the other as a common return.

Another type of detecting unit, commonly referred to as the "electric eye," utilizes two beams of light projected across the highway and focused on photoelectric cells. This method would seem to be ideal since no visible contacting device is laid across the highway that might attract the motorists' attention. However, this method cannot be easily adapted for use in determining the speeds of vehicles in more than one direction.

Still a third type of detecting unit developed by the Public Roads Administration employs two pneumatic detectors, each consisting of a flexible rubber tubing laid across the road and terminated at both ends by air switches. This unit has been used almost exclusively by the Administration with considerable success, and has proved to be superior to the other types mentioned from the standpoints of operation, portability, ease of installation, durability, and cost. The pneumatic detector has been described in detail in the January 1939 issue of PUBLIC ROADS. Slight modifications of the original design will be discussed later.

NEW TYPE OF SPEEDMETER DEVELOPED

Most of the speedmeters that have been developed by other agencies have employed an electronic timing unit based on the principle of the vacuum tube voltmeter. This consists of a charged condenser biasing the grid of a vacuum tube. When a vehicle actuates one of the switches in the detecting unit, the charged condenser commences to discharge through a resistor. The second switch in the detecting unit, upon being actuated by the vehicle, stops the discharge. The amount of discharge is dependent upon the time consumed by the vehicle in traveling the fixed distance between the two switches of the detecting unit. The remaining charge on the condenser causes a definite measurable current to flow through the vacuum tube. The recording unit is in this case a sensitive meter with a scale which has been calibrated to indicate the speed directly in miles per hour.

The Massachusetts Highway Traffic Research Project developed a speedmeter [1] using a timing unit as described above. A more elaborate electronic speedmeter was developed in Illinois by Reich and Toomin.[2] Careful studies were made of both of these electronic speedmeters and although both possessed many desirable characteristics, they also had certain disadvantages.

Development work by the Public Roads Administration resulted in the production of an entirely new speedmeter incorporating a pneumatic detecting unit, an electromechanical timing unit, and either of two types of recording units.

The pneumatic detecting unit is comprised of two rubber tubes, each 28 feet long and terminated at both ends by air switches. An insulated wire installed inside of each tube serves as the positive return lead from the air switches on the far side of the road to the recording equipment. A single insulated wire laid adjacent to one of the rubber tubes serves as the common negative return lead of the electric circuit. Each tube has a dead section approximately 5 feet long which is centered at the center of the pavement. This arrangement permits detection by lanes since each end of the tube is terminated by an air switch and operates independently. The dead section prevents a vehicle from actuating the two air switches at the two ends of a tube simultaneously should the vehicle straddle the center of the pavement.

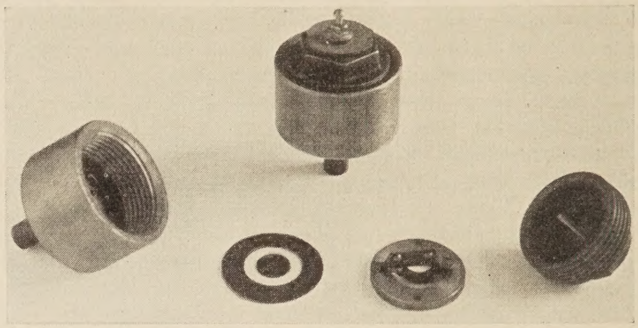

FIGURE 1.—ASSEMBLED AIR SWITCH (TOP) AND COMPONENT PARTS.

Formerly, this dead section was created by simply punching holes through the walls of the tube. This method proved to have some disadvantages when the pavement was wet because the suction resulting from the displacement of air by passing vehicles would draw water into the tube and render the operation erratic. On the other hand, there were certain advantages in perforating the tubing. It permitted equalization of air pressures inside and outside the rubber tubing to be quickly established after passage of the wheels over the tubing; it eliminated the effects of air surges; and it prevented false operation due to changes in temperature. These advantages were particularly important whenever pneumatic detectors were used in connection with traffic counters, but for use with the speedmeter the only significant factor was freedom from temperature effects. In the closed tube that was finally adopted the effects due to changes in temperature were eliminated by making a pinhole in the rubber diaphragm of the air switch. In the final design the dead section was obtained by sealing off a section of the tube.

The air switch employed in the pneumatic detector is shown in figure 1. This unit is much more rugged than the modified engine oil-pressure gage formerly used, and is readily accessible for adjustment. It is constructed of commercially available parts and standard pipe fittings.

TIMING AND RECORDING UNITS DESCRIBED

The timing unit makes use of an electromechanical stepping switch of the type employed in automatic telephony and known as the Strowger 50-point rotary switch. This switch consists of a number of wipers mounted on a shaft which is rotated by a pawl-and-ratchet mechanism actuated by an electromagnet. The wipers are thus stepped around over a number of fixed contacts arranged in an arc. Since the wipers revolve at a definite speed, the amount of their angular movement is a measure of time.

The contacts are grouped in a semicircular rigid unit called a "bank." This bank consists of 4 levels with 25 contacts per level. The wipers have a single wiping end and are arranged in pairs; 1 wiper in a pair is set

[1] Scientific American, March 1936, vol 154, No. 3, p. 122.
[2] Review of Scientific Instruments, December 1937, vol. 8, No. 12, p. 502.

180° behind the other on a separate level of contacts. The 2 wipers constituting a pair are electrically connected in parallel. Thus, through the 2 wipers, access is had first to 1 level of 25 contacts, and then to another level of 25 contacts, a total of 50 contacts per revolution of the wiper shaft.

The electromagnet driving the switch employs a self-interrupted circuit. Upon operating, it opens its own circuit, then restores, thus closing its own circuit, in principle resembling the action of an electric buzzer. With such a circuit arrangement, the factors which limit the rotary speed are the electrical characteristics of the driving magnet and the mechanical construction of the switch mechanism. The construction of the rotary switch is such that a rotary speed of 55 contacts per second is attained. A complete description of the construction, mechanical operation, and adjustments of the rotary switches has been published elsewhere.[3] It will suffice here to state that the adjustments for the rotary switches are simple and few in number. Operation of the Strowger switch is controlled by a set of quick-acting relays electrically connected to the air switches and actuated by the latter. Motion of the wipers is invariably arrested when one wiper is in contact with one of the 50 contacts on its corresponding level, and through the associated equipment a separate electrical circuit is closed to one of many recording elements in the recording unit.

Under certain conditions a single timing unit can be used successfully on a two-lane highway; however, for this purpose the Administration has adopted a dual timing unit as shown in figure 2, consisting of two Strowger rotary switches adjusted to the same frequency and connected to separate recording units that record speeds independently by lanes.

Either of 2 types of recording units may be employed with the timing unit. One type consists of a standard 20-pen graphic time recorder, mentioned previously, which utilizes a strip chart. By using a novel circuit arrangement made possible by an additional level of contacts on the Strowger switch, the 20-pen recorder was virtually converted into a 39-pen recorder. As shown in figure 3, 2 sets of contacts, consisting of 19 consecutive contacts each, were connected in parallel, each pair of contacts being connected to an individual recording pen. The first set of 19 contacts is connected to pens numbered 1 to 19, inclusive, in the recorder and indicates high speeds in the first half of the speed range. The second set of 19 contacts in conjunction with pen No. 20 corresponds to the second half of the speed range, the low speeds. Pen 20, by virtue of its connection to the additional level of contacts, serves as an indicator of low speeds, differentiating between the high and low speed ranges.

Referring to figure 4, a high speed is indicated by the movement of 1 of the first 19 pens, as exemplified by A, whereas a low speed is indicated by the simultaneous movement of pen 20 and any 1 of the other 19 pens, as shown by B. Pen 1, when operating alone, as shown by C, serves to indicate speeds higher than the calibrated range of the speedmeter. Likewise, pen 20, when operating alone, as shown by D, indicates speeds lower than the normal calibrated range of the speedmeter. Moreover pen 20 serves to indicate the direction of travel of a vehicle opposite to that normally recorded by the recorder, as in the case of one vehicle

[3] Characteristics of Strowger Switches, by K. W. Graybill, Circular No. 1641 Automatic Electric Co., Chicago, Ill.

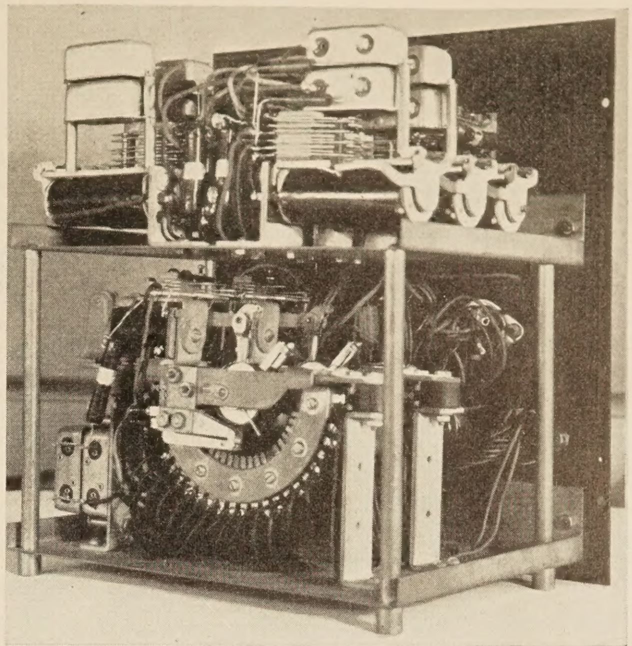

Figure 2.—Timing Unit Used When Studying Traffic in Two Lanes.

passing another vehicle within the fixed distance between the detectors.

To accomplish the recording of the speed and direction of the vehicle performing the passing, the operator depresses a lever-type key that reverses the sequential order of operation of the detectors in the lane occupied by the passing vehicle, upon its approach to the fixed detecting zone. The operator releases the reversing key after the passing vehicle has left the detecting zone. When the reversing key is depressed, pen 20 operates and remains in the operated position for the duration of the recording. A high speed recording is shown by E. It will be noted that in this example, pen 20 was interrupted during the recording of another pen, whereas in the case of a low speed recording shown by F, pen 20 is not interrupted during the recording of another pen. If pen 20 is interrupted during the recording of pen 1, as shown by G, speeds above the range of the speedmeter are indicated. If no other pen records while the reversing key is depressed, pen 20 indicates speeds below the range of the speedmeter as shown by H.

OPERATION OF SPEEDMETER OUTLINED

Figure 5 shows a speedmeter employing two 20-pen graphic recorders. The third graphic recorder shown in this figure is used in connection with a placement detector for recording the transverse positions of vehicles and will be discussed later.

The second type of recording unit consists of a bank of 20 counters of the type employed as telephone call registers. Each counter is individually connected to a separate group of contacts, ranging from 1 to 4 contacts per group, on 2 levels of the Strowger switch, as shown in figure 6. The circuit is arranged so that counter No. 1 records speeds above the calibrated range of the speedmeter and counter No. 20 records speeds below the range of the speedmeter. The calibrated range of speeds is recorded on counters Nos. 2 to 19, inclusive. Each counter records a group of speeds as determined by the number of contacts to which it is connected. In contrast with the other recording unit, this type does not record individual speeds but simply

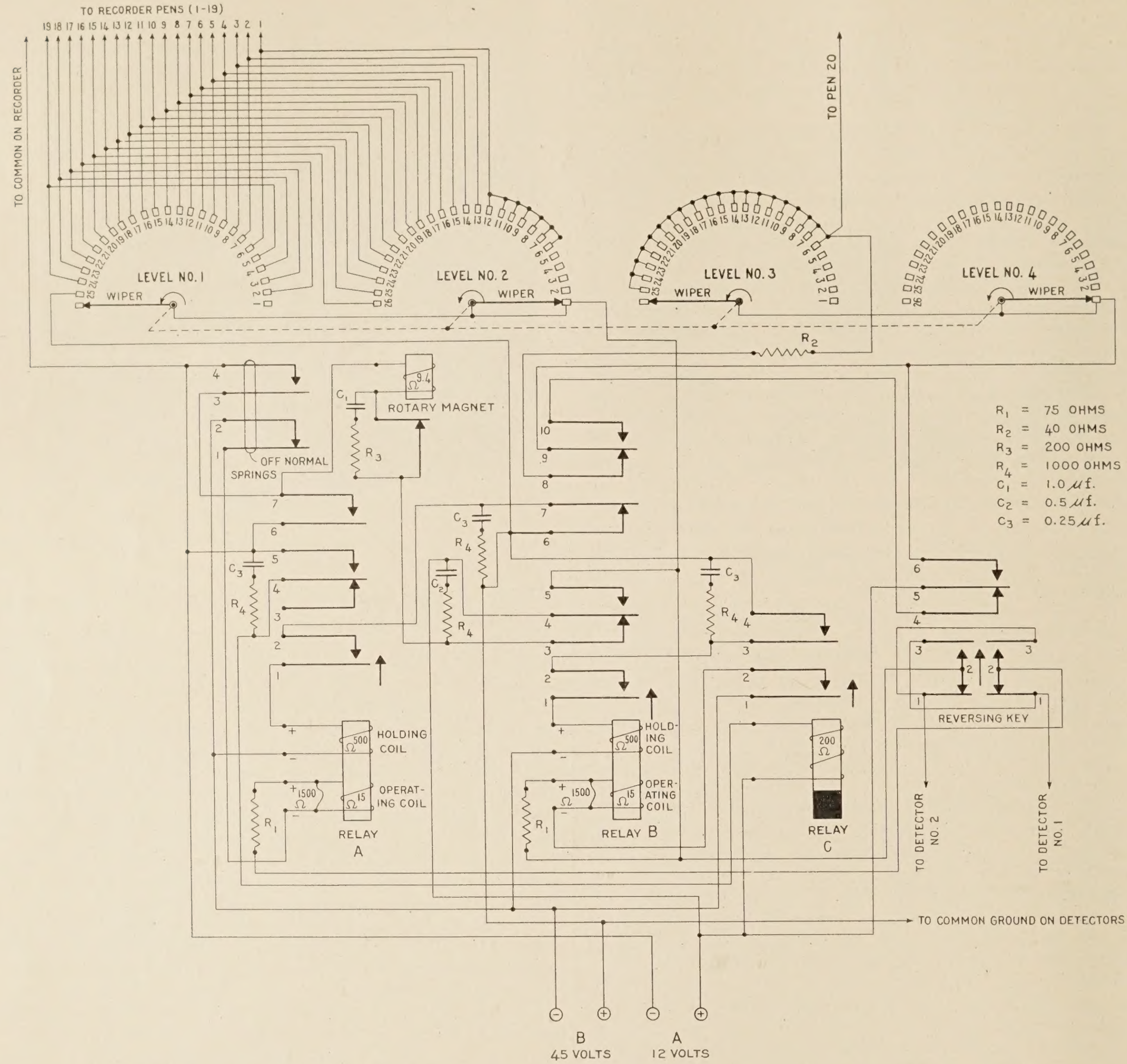

Figure 3.—Wiring Diagram of Single Timing Unit for Use With a 20-Pen Graphic Recorder.

accumulates the group speeds on the series of counters. No provision is made for indicating direction of travel although the circuit arrangement permits the use of the manually controlled direction-reversing key.

Figure 7 shows a speedmeter employing a single 20-counter recording unit.

Referring to the circuit diagram shown in figure 3, the operation of the speedmeter is as follows: Upon actuation of detector 1 by the front wheels of a vehicle, a circuit to relay A is closed causing relay A to pull up in 0.0015 second, closing contacts 1 and 2, 4 and 5, and 6 and 7 simultaneously. Contacts 1 and 2 close a circuit to the holding coil which serves to keep relay A in the operated position. Contacts 4 and 5 close a circuit causing relay C to operate. Contacts 6 and 7 close the circuit to the rotary magnet on the Strowger switch, thus causing all wipers to commence rotating in a counterclockwise direction.

It will be noted that the wipers on levels 2 and 4 sweep over the contacts during the first half of a revolution and wipers on levels 1 and 3 during the second half of a revolution. The upper speed range is covered by the contacts on level 2. The unused contacts on level 2 represent excessive speeds above the desired range. The speed range commences with contacts 6 to 12, inclusive. These are wired in multiple and connected to recording pen 1, which represents speeds above the calibrated range. At the same instant that the wipers commence to rotate, contacts 1 and 2 on the "off-normal springs" open and contacts 3 and 4 close. This is effected by means of the off-normal arm (not shown) mounted on the wiper shaft. Contacts 1 and 2 upon opening serve to open the detector circuit to the operating coil of relay A, preventing false operation by another vehicle during the ensuing period. It will be noted that contacts 3 and 4 on the

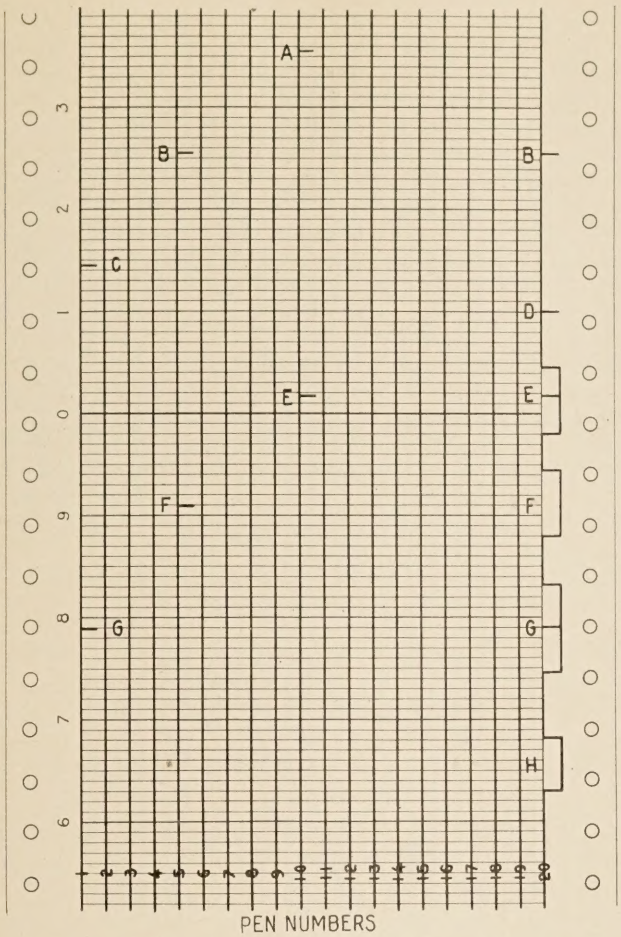

FIGURE 4.—TYPICAL STRIP CHART RECORD SHOWING:

	Normal direction	*Opposite direction*
High speed	A	E
Low speed	B	F
Speeds above range	C	G
Speeds below range	D	H

off-normal springs parallel contacts 6 and 7 on relay A. Their purpose will be explained later.

Rotation of the wipers is interrupted whenever a vehicle upon actuating detector 2 causes relay B to operate. Relay B is electrically interlocked with relay C to prevent false operation; furthermore, relay B cannot operate unless relay A has been operated first, since relay A operates relay C. This interlocking circuit through relay C is for the purpose of insuring proper sequence of operation of the detectors and also to prevent false recording of speeds in the interval of time remaining after the speed of one vehicle has been recorded. Relay B upon operating within 0.0015 second simultaneously closes contacts 1 and 2, 4 and 5, 9 and 10, and opens contacts 3 and 4, 6 and 7, and 8 and 9.

The closing of contacts 1 and 2 completes the circuit to the holding coil of relay B causing relay B to stay operated. At the same time, the circuit to the rotary magnet is opened through contacts 3 and 4, thus stopping the rotation of the wipers. Contacts 4 and 5 upon closing complete a circuit to the recording element through the corresponding contact on the level and its wiper. The wiper remains stationary on the level contact for only 0.03 second, which is the time required to actuate the recording element. This time is controlled by the slow-release relay C. The opening of contacts 6 and 7 on relay B causes relay A to drop out to its normal position; whereupon relay A causes the slow-release relay C to open after a delay of 0.03 second. When relay C is de-energized, contacts 3 and 4 on relay C open the circuit of the holding coil on relay B causing relay B to release to its normal position. Relay B upon releasing in 0.0015 second, permits contacts 3 and 4 again to close the circuit to the rotary or driving magnet causing the wipers to resume rotation for the remaining part of the revolution—back to their normal position.

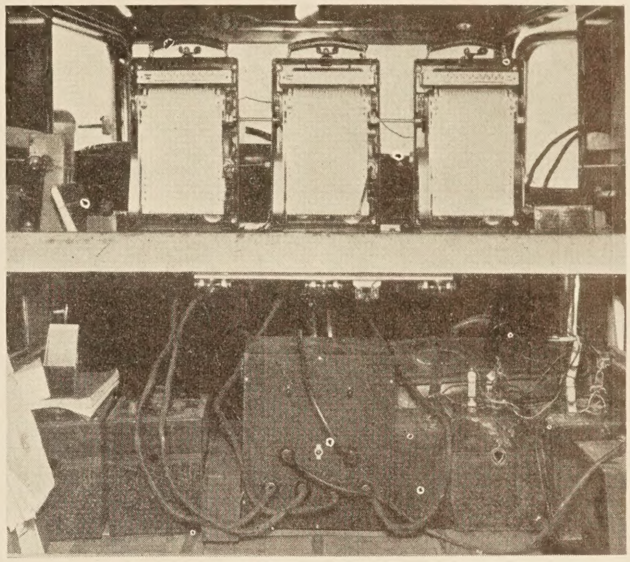

FIGURE 5.—GRAPHIC RECORDERS (TOP) AND SPEEDMETER USED FOR STUDYING TRAFFIC IN TWO LANES IN SPEED-PLACEMENT STUDIES.

The resumption of rotation is referred to as "homing." During this period the detector circuits remain open until the wipers reach their home position, at which time the off-normal arm on the wiper shaft closes contacts 1 and 2 and opens contacts 3 and 4 on the off-normal springs. The closing of contacts 1 and 2 permits relay A to be operated again upon actuation of detector No. 1. The opening of contacts 3 and 4 stops the rotation of the wipers. The speedmeter is again in position for repeating the above cycle of operation.

TWO METHODS AVAILABLE FOR CALIBRATING SPEEDMETER

Either of two methods can be used in calibrating the speedmeter. In the first method, the frequency of the Strowger switch, in contacts per second, is determined from one revolution of the wiper shaft. The off-normal arm, that is mounted on the wiper shaft, opens and closes contacts 1 and 2 on the off-normal springs once for each revolution of the wiper shaft. The time taken for one complete revolution can be determined by means of a photographic oscillograph employing a D'Arsonval galvanometer. The oscillograph is connected in series with contacts 1 and 2 and a battery of low voltage provided with a suitable current limiting resistor to give proper deflection of the galvanometer. Use of contacts 1 and 2 for this purpose is made prior to connecting them into the circuit of relay A, as shown in figure 3.

A typical oscillogram obtained on a high-speed oscillograph using 35-millimeter motion-picture film is

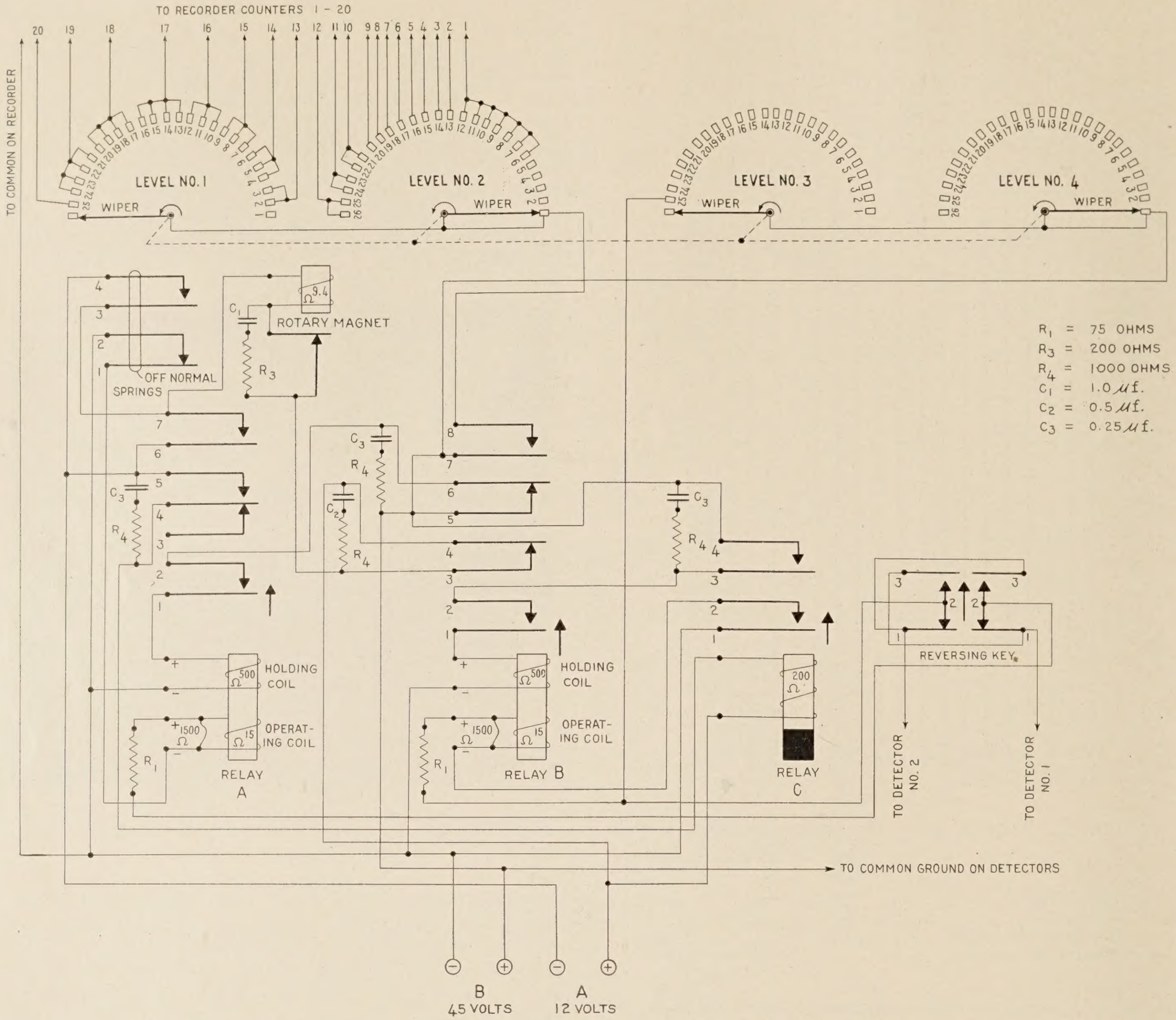

Figure 6.—Wiring Diagram of Timing Unit for Use With a 20-Counter Recorder.

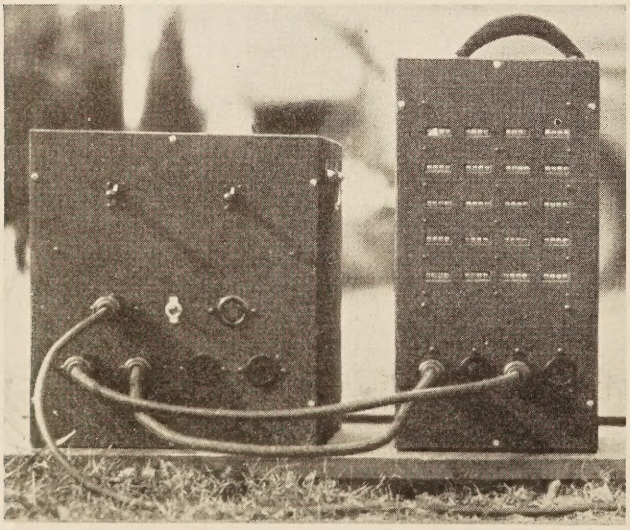

Figure 7.—Speedmeter Using a Single 20-Counter Recording Unit, Used for Studying Traffic in Two Lanes.

shown in figure 8. As determined from this oscillogram, the time required for one complete revolution is 0.860 second. A and B denote, respectively, the opening and closing of contacts 1 and 2 on the off-normal springs. By dividing 50 by 0.860, the Strowger frequency of 58.2 contacts per second is obtained. Having obtained the Strowger frequency, the calibration may be completed graphically from the curves as shown in figure 9, or mathematically as will be shown later.

Referring to figure 9, the Strowger frequency is shown by the straight-line curve. The hyperbolic curves are speed versus time curves for three detector spacings. From these curves the maximum speed for each contact is obtained, beginning with contact 13 which represents pen 2 in the graphic recording unit; contact 14 which represents pen 3, etc. A complete calibration for the speedmeter using a 20-pen graphic recorder and a detector spacing of 24 feet is shown by table 1. A complete calibration for the speedmeter using a single 20-counter recording unit and a detector spacing of 24 feet is shown by table 2.

The second method that may be employed in calibrating the speedmeter uses a stroboscopic photoelectric timing device developed by the Administration. This device, shown in figure 10, consists of an electrically driven turntable whose periphery is precisely graduated into 200 equal divisions. Mounted on the turntable are two vertical shields; one permanently mounted at the zero index, the other adjustable angularly along the graduated scale. Upon rotation of the turntable, these shields serve to interrupt a horizontal beam of light that is projected into a photoelectric cell which in turn actuates a relay. A second relay of the slow-release type is controlled by the photoelectric relay and functions as a single-pole, double-throw switch, switching alternate pulses of the photoelectric relay in response to the interruptions of the light beam. These pulses simulate the actuation of the two detectors by a vehicle and are transferred to the speedmeter through this switching relay which is manually reset for each interval of time used in calibrating the speedmeter.

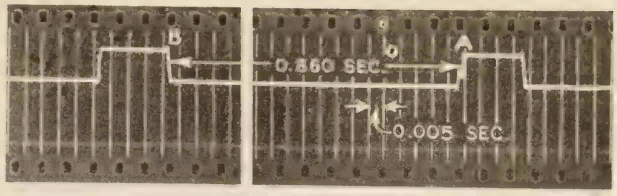

FIGURE 8.—OSCILLOGRAM OBTAINED FOR SPEEDMETER CALIBRATION.

The electrically driven turntable is a modified conventional type using a 110-volt, alternating-current induction motor that is governor-controlled. Since the standard turntables that are equipped with synchronous motors are designed for speeds other than the desired speed of 60 r. p. m., the induction motor type was

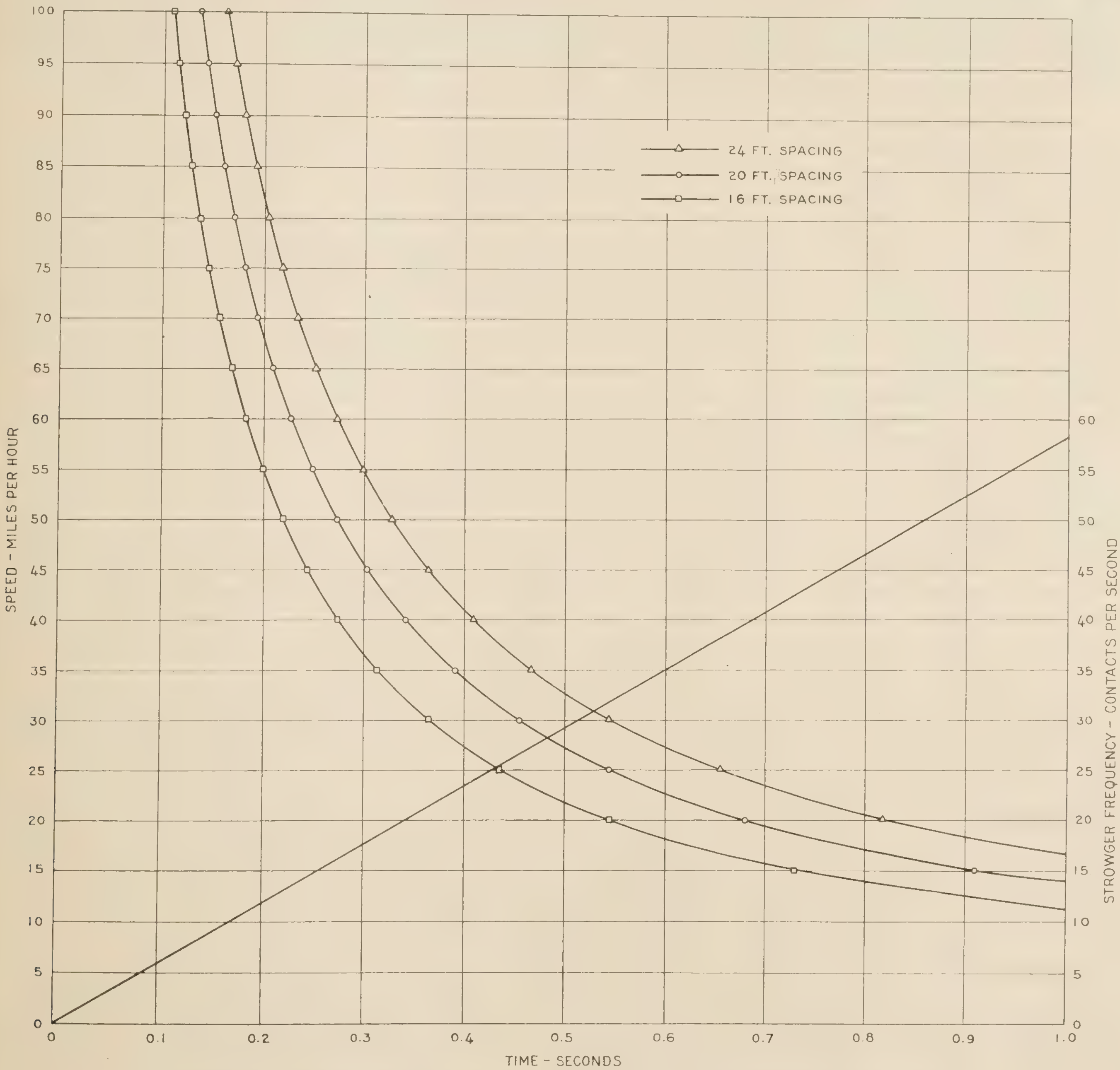

FIGURE 9.—SPEEDMETER CALIBRATION CURVES FOR VARIOUS DETECTOR SPACINGS.

Table 1.—*Calibration for speedmeter, detectors spaced 24 feet apart*

Contact No. (C)	Recorder pen No.	Maximum speed	Difference	Maximum variation	Average speed
		M. p. h.			*M. p. h.*
12	1	79.3	6.1	±3.05	76.2
13	2	73.2	5.2	2.6	70.6
14	3	68.0	4.5	2.25	65.7
15	4	63.5	4.0	2.0	61.5
16	5	59.5	3.4	1.7	57.8
17	6	56.1	3.2	1.6	54.5
18	7	52.9	2.8	1.4	51.5
19	8	50.1	2.5	1.25	48.8
20	9	47.6	2.2	1.1	46.5
21	10	45.4	2.1	1.05	44.3
22	11	43.3	1.9	.95	42.3
23	12	41.4	1.7	.85	40.5
24	13	39.7	1.6	.8	38.9
25	14	38.1	1.4	.7	37.4
26	15	36.7	1.4	.7	36.0
27	16	35.3	1.3	.65	34.6
28	17	34.0	1.1	.55	33.4
29	18	32.9	1.1	.55	32.3
30	19	31.8	1.1	.55	31.2
31	1 & 20	30.7	.9	.45	30.2
32	2 & 20	29.8	.9	.45	29.3
33	3 & 20	28.9	.9	.45	28.4
34	4 & 20	28.0	.8	.4	27.6
35	5 & 20	27.2	.7	.35	26.8
36	6 & 20	26.5	.7	.35	26.1
37	7 & 20	25.8	.7	.35	25.4
38	8 & 20	25.1	.7	.35	24.7
39	9 & 20	24.4	.6	.3	24.1
40	10 & 20	23.8	.6	.3	23.5
41	11 & 20	23.2	.5	.25	22.9
42	12 & 20	22.7	.5	.25	22.4
43	13 & 20	22.2	.5	.25	21.9
44	14 & 20	21.7	.5	.25	21.4
45	15 & 20	21.2	.5	.25	20.9
46	16 & 20	20.7	.4	.2	20.5
47	17 & 20	20.3	.4	.2	20.1
48	18 & 20	19.9	.4	.2	19.7
49	19 & 20	19.5	.4	.2	19.3
50	20	19.1	-------	------	

Table 2.—*Calibration for 20-counter speedmeter, detectors spaced 24 feet apart*

Counter No.	Maximum speed	Difference	Maximum variation	Average speed
	M. p. h.			*M. p. h.*
1	79.3	6.1	±3.05	76.2
2	73.2	5.2	2.6	70.6
3	68.0	4.5	2.25	65.7
4	63.5	4.0	2.0	61.5
5	59.5	3.4	1.7	57.8
6	56.1	3.2	1.6	54.5
7	52.9	2.8	1.4	51.5
8	50.1	2.5	1.25	48.8
9	47.6	2.2	1.1	46.5
10	45.4	4.0	2.0	43.4
11	41.4	3.4	1.7	39.7
12	38.0	2.9	1.45	36.5
13	35.1	2.4	1.2	33.9
14	32.7	3.0	1.5	31.2
15	29.7	2.5	1.25	28.4
16	27.2	2.2	1.1	26.1
17	25.0	2.4	1.2	23.8
18	22.6	2.0	1.0	21.6
19	20.6	1.5	.75	19.8
20	19.1	--------	--------	--------

selected because it permitted this speed to be obtained by a slight adjustment of the governor that is controlled manually. The speed of the turntable is maintained constant through the use of a stroboscope. A stroboscope disk is mounted on the turntable and a neon lamp with a reference index is mounted directly over the disk. Since the turntable revolves at the rate of 1 revolution per second, each of the 200 divisions on the graduated scale represents 0.005 second. Obviously, any fraction of a second can be obtained by adjustment of the movable shield, although for all practical purposes sufficient precision is obtained in selecting intervals of time to within a half of the smallest division, i. e., 0.0025 second.

In calibrating the speedmeter (fig. 11), several intervals of time are selected and the operation of pens corresponding to these intervals is noted. The maximum time for each interval is established by increasing the time until an adjacent pen in the recorder operates. By plotting the maximum time versus Strowger contacts, a straight-line relation such as that shown in figure 9 is obtained which indicates the Strowger frequency.

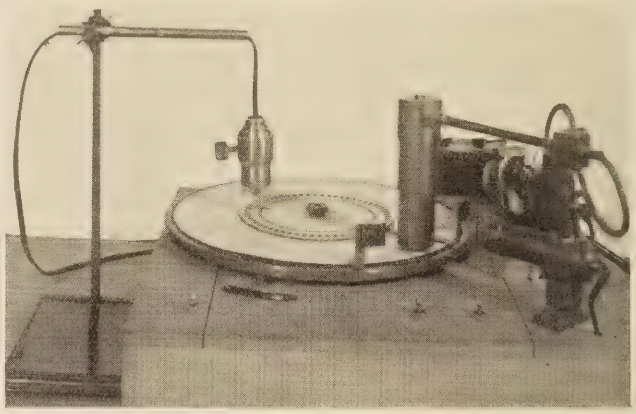

Figure 10.—Photoelectric Stroboscopic Timing Device Used in Calibrating Speedmeter.

CALIBRATION DATA MAY BE EASILY CALCULATED

The calibration data shown in table 1 may be obtained more rapidly and accurately by a simple mathematical means.

It is assumed that the vehicle is moving at a constant speed during the time of the measurement and it is known that during this time the wiper of the Strowger switch is moving over its contacts at a uniform rate. These two motions can be simply expressed and related for the common time interval so as to give directly the number of the contact point on which the wiper will stop for any vehicle speed and detector spacing.

The motion of the vehicle may be expressed as

$$S=\frac{D}{t}$$

in which S=speed,
D=distance (between detectors),
t=time of transit.

As already pointed out, this relation is shown graphically by the hyperbolic curves in figure 9.

The travel of the Strowger switch wiper may be expressed thus

$$C=ft$$

in which C=the number of the contact on which the wiper will stop,
f=the switch frequency,
t=the time during which the Strowger switch is operating.

This is the equation of the straight line in figure 9.

The time under consideration is common to both movements permitting the equating of the two expressions. This results in the equation

$$S=\frac{Dfk}{C}$$

in which S=vehicle speed in miles per hour,
D=detector spacing in feet,
f=Strowger switch frequency in contacts per second,
C=the number of the switch contact on which the wiper will stop,
k=a conversion constant (0.682) which permits S to be expressed in miles per hour.

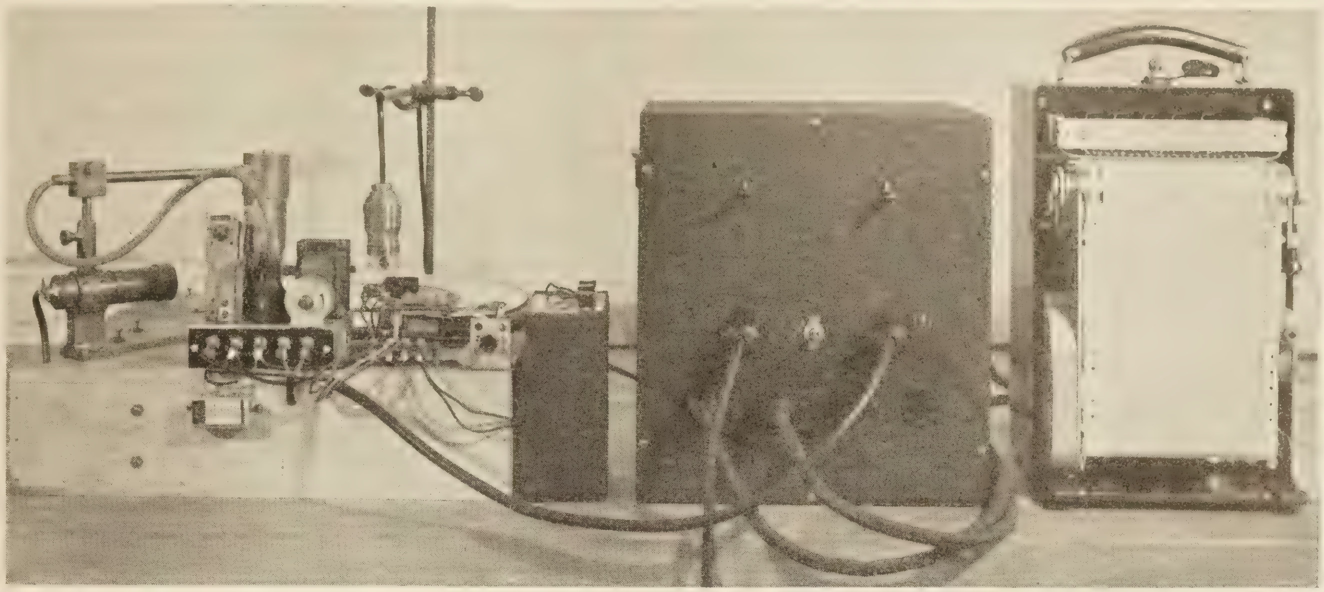

FIGURE 11.—PHOTOELECTRIC STROBOSCOPIC TIMING DEVICE BEING USED TO CALIBRATE SPEEDMETER.

In this expression it is apparent that for any given switch frequency and detector spacing, S and C are the only variables.

When calculating speed values, such as are shown in table 1, the maximum speeds listed in the third column are based on the corresponding values of C given in the first column. The average speed values shown in the sixth column may be calculated directly with the formula by assigning values of 12½, 13½, 14½, etc., to C.

Once the speedmeter is calibrated, it is capable of retaining its calibration over a long period of usage. Periodic checks on the calibration have revealed the remarkable stability of the Strowger switch frequency. This feature accounts for its chief advantage in field use, eliminating the necessity of hourly or daily calibration, as required by other types of speedmeters. In one instance, the speedmeter was in use for over 175 hours, recording the speeds of approximately 60,000 vehicles, during which time the calibration remained constant.

The speedmeter can be adapted for other purposes in connection with traffic safety. By certain modifications, it can be used to control the lighting of warning signs to speeders on the highway and simultaneously to actuate a signal at highway patrol police stations indicating presence and direction of travel of the speeder on the highway. The device can also be adapted to control traffic lights in vehicular tunnels for the purpose of regulating the flow of traffic.

TRANSVERSE POSITIONS OF VEHICLES IMPORTANT

Simultaneously with the development of the speedmeter, a device by which the transverse positions of vehicles on the pavement could be automatically recorded was being developed. Such information is needed for two purposes: (1) To determine economical lane widths for various speeds and types of traffic; and (2) to study the behavior of traffic under various highway and roadside conditions. These two purposes are closely related, yet entirely distinct from one another.

Analysis of the transverse positions of vehicles on the highway requires a delimiting of their paths. Under normal conditions, with no interfering traffic, vehicles will travel at such distances from the center or edge of the pavement as the inclinations or habits of the drivers dictate. It is to be expected that the majority of vehicle paths will be concentrated on a portion of the pavement only slightly wider than the average car. If the few extreme cases are excluded, the area along the pavement traversed by the remaining large majority of the vehicles will define the vehicle path on that particular highway. If the cross section is properly designed and vehicular movement is reasonably controlled, it may be expected that this path will lie well within the proper traffic lane. If, however, shoulders are poor or lane widths are too narrow, this path may be shifted toward the center of the pavement until it may even overlap the normal path of vehicles traveling in the opposite direction, with consequent increase in hazard. On a well-designed road, properly used, this path should parallel the center line, neither swerving toward the edge when meeting vehicles moving in the opposite direction nor veering toward the center when passing roadside objects such as culvert headwalls, bridge abutments, posts, or trees.

The determination of the most appropriate combination of lane width and shoulder width and type on normal tangent alinement is thus the first purpose of these studies. The second main purpose is to discover the effect on normal driving practice of curves of varying degrees, of the presence of roadside objects such as guardrails, narrow culverts, and other objects encroaching on the normal shoulder width, and of high curbs, overgrown shoulders, or other features which may have a considerable psychological effect on the driver.

These studies are directed toward economy of highway construction, for they will show, not only how wide traffic lanes should be, but also how narrow they can be, and whether the use of a paved shoulder may have the effect of a greater lane width by inducing vehicles to travel nearer the edge of the pavement. They will also have an equal if not greater value as a means of studying traffic safety, particularly as it is affected by highway design.

Practically all attempts to analyze the causes of accidents have been based upon the questioning of the drivers involved or upon attempted reconstruction of the events immediately preceding accidents. General observations of driver behavior and detailed studies of

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driving practice, in other phases of the special studies now being conducted by the Public Roads Administration, lead to the belief that it is remarkable, not that so many accidents occur, but that they are so few in number. While many obvious examples of faulty driving are found when accidents occur, a far greater number are found in normal traffic movement in which no accidents occur. The reason that these faulty practices did not result in misfortune is that all the conditions necessary for an accident were not present. If any features of the design of the highway are responsible for or contribute to faulty driving which occasionally produces collisions or mishaps, they can be detected far more readily by a study of the behavior of the tens or hundreds of thousands of vehicles that move without mishap, whether or not safely, than by the most critical examination of the actions of the few that are unfortunate because circumstances combined against them.

The device that has been developed to permit the recording of this vehicle path, or the transverse positions of all vehicles, employs for its detecting element a modification of a so-called positive-contact detector previously developed and patented by the Public Roads Administration and used in other studies. This original detector consisted of two spring-steel strips 20 feet long, separated from one another by means of a rubber arch. This arch is depressed by the passage of a vehicle, thus bringing the strips into contact and completing an electrical circuit. This detecting element was encased in still another arch of similar type to exclude moisture. With lead wires connected to the steel strips, it has served very effectively for the detection of vehicles when used with automatic traffic counters.

Modification of this detector to permit the recording of transverse position required the dividing of one of the steel strips into a number of individual segments, to each of which a separate lead wire is attached. Vehicles passing over the strip then deflect individual sections of the strip and make contacts only at points corresponding to the positions of the wheels on the pavement. Each of the lead wires is connected to an individual pen in the same type of graphic time recorder used in the other phases of this study so that the wheel positions are automatically recorded on the strip chart. Individual segments are 1 foot long, divided into a "live" section 7½ inches long and a "dead" section 4½ inches long. This combination of live and dead sections insures the recording of all wheels but prevents, for most vehicles, the recording of the same wheel on adjacent segments. Vehicles equipped with unusually wide tires or with dual tires will actuate two, or perhaps more, adjacent segments, but it has been found in practice that passenger cars seldom are so recorded. Thus trucks and busses are almost invariably self-identified even without the manual classification normally made as an integral feature of these studies.

EQUIPMENT USEFUL IN MAKING MANY TYPES OF STUDIES

As a result of this development work, there are now available and in operation three distinct types of apparatus adapted either for use independently or in combination with one another. The first is the speed counter with which vehicle speeds may be determined and their records accumulated on a series of counters. This device is useful where general observations of traffic speed are desired. Average speeds and speed distribution may be determined accurately, the results being available almost immediately upon completion of the field work. Typical uses are found in studies of the effect on speed of highway lighting, of enforcement policies, or of various features of the highway design in which identification of particular vehicles is unimportant.

The second type of apparatus is the speedmeter, with which the speed of each vehicle may be measured and, by means of a related graphic recorder, individually and automatically recorded. It is more precise in its record than the speed counter, and is useful wherever the speeds of individual vehicles must be identified. The results may be obtained only after the chart records have been transcribed in the office. The feature of individual vehicle recording is essential in a study of highway capacity.

The third type of apparatus is the placement detector, with which the transverse positions of all vehicles are separately recorded. Since speed is expected to be a factor in vehicle placement, this device is invariably used in combination with the speedmeter.

The speed records collected in conjunction with the placement records are those needed in an analysis of highway capacity. Similarly, if the placement detector is used in conjunction with the speedmeter at the locations where studies of highway capacity are being conducted, information on vehicle paths will be automatically collected as a byproduct of the capacity study. It has been customary, therefore, to collect complete information on both phases of the work at every location studied, regardless of the primary purpose of the operation at any particular spot.

There are distinct differences in the conditions that are important in either of these types of studies, however, even though the analyses are based on the same type of data, and generally it is not possible to schedule a single series of observations to satisfy the requirements of both studies. Accordingly, the work of a particular study is seldom directed equally toward the two different objectives, but rather is concentrated on the one objective of primary importance, with the additional data considered as an inexpensive yet valuable byproduct.

In addition to satisfying these primary requirements, the equipment has made possible a variety of studies not heretofore possible because means of conducting them had been inadequate or completely lacking. Among special purpose studies that have been considered but on which work has not yet been undertaken are the following:

1. *Effect of curvature and superelevation.*—The degree of curve that can be permitted and the superelevation that must be introduced in order to encourage vehicles to negotiate curves without tendency to deviate from their proper traffic lanes may be readily studied with this equipment.

2. *Effect of spiraling.*—By installing the speed and placement detectors at various points along curves and for short distances preceding or following them, the effect of any such treatment may be evaluated. This type of study may be based upon a determination of the average paths of all vehicles at the different points or, by some modification of the apparatus, the paths taken by particular vehicles as they traverse the curve may be observed.

3. *The effect of vehicle length.*—The extent to which long vehicles or combinations such as tractor-truck semitrailers tend to track off line and thus require additional pavement width on curves, whether proper superelevation will eliminate this effect, or whether side slippage of the rear wheels of a trailer, under certain

conditions, might have the reverse effect, can be readily determined. In addition to determining the speeds and positions of such vehicles, the wheelbase lengths may also be recorded without requiring that any vehicles be stopped or otherwise measured.

4. *The effect of special design features, as at intersections.*—The areas of pavement used by vehicles in negotiating intersections or other special highway design features may be investigated by the placement detectors to assist in eliminating unused areas in future designs.

RECORD CHARTS EASILY ANALYZED

In the use of these devices, one speedmeter is normally required for each lane of traffic to be observed, although in very light traffic or for special purposes one speedmeter may be made to serve for more than one lane by providing detectors for each lane and a related switch to make either detector operative as desired. Generally, provision is made for complete records on a two-lane road by incorporating into one unit of equipment two speedmeters and one placement detector each connected to one of three mechanically coupled graphic recorders. For three- or four-lane roads, one unit is installed on either side of the road, and the two are synchronized by simultaneous records made with a telegraph key in series with one pen in each graphic recorder.

Two men are required to operate each unit which is installed in a light panel-body truck or station wagon, enabling work to be conducted under all light and weather conditions. The detectors are placed at the desired point on the road surface and the truck concealed from view well off the road. Figure 12 shows the detectors as installed in a typical set-up. Strips 1 and 4 are the speedmeter detectors, strip 2 is the placement detector, and strip 3 is a detector for an automatic counter used so that the observer may check the rate of traffic flow at any time.

Although the speedmeters function automatically so long as traffic moves normally in the proper lane, the direction of the meters must be reversed in case one vehicle passes another or for some other reason occupies the left lane. Commercial vehicles are classified as they pass, and by means of a telegraph key in series with one graphic recorder pen, each is recorded on the chart in a suitable code symbol in accordance with whether it is a light, medium, or heavy truck or a bus. Tractor-truck semitrailer and truck-trailer combinations can be identified on the chart by the number of axles recorded by the placement detector. In addition to this constant classification of the traffic, the time of day is indicated on the charts at regular intervals, again by telegraph key and a suitable code, so that the chart speed may be accurately checked and the records later broken down into any desired time periods.

Mechanization of the field procedure has virtually eliminated the personal element in the accuracy of the recording, an important factor in work that is rapidly expanding and consequently must be performed by many different individuals. Further, the standardized equipment not only improves the accuracy of the particular studies, but insures that all studies will be made on a comparable basis. Of great importance also, is the reduction in cost. Field work under this new procedure costs less than one-third, and analysis less than one-fourth, the cost using earlier methods.

Two units of this equipment, to permit observations on roads up to four lanes in width, have been in practically continuous use since July 1939 by the Public Roads Administration in cooperation with interested States, generally through the planning survey organizations. Work has been conducted on highway capacity and vehicle behavior in Massachusetts, Illinois, and Texas. Special driver studies have been conducted in Connecticut and South Carolina in conjunction with the American Association of Motor Vehicle Administrators. Special studies of the effect of highway lighting were conducted in Ohio. Further studies are scheduled in other States for the spring and summer of 1940. Other units are being assembled expressly to be loaned to interested States to permit them, with their own highway planning survey personnel, to conduct exhaustive vehicle-behavior studies. One such unit has already been used in Minnesota, and others will be available shortly for further studies already agreed upon. With such active participation long-needed data on the effectiveness of different highway designs will rapidly become available.

FIGURE 12.—SPEEDMETER AND PLACEMENT DETECTORS INSTALLED ON A TWO-LANE ROAD.

As an example of the type of data obtained, figures compiled from a portion of the records obtained at one location in Massachusetts are presented. This concrete road was 20 feet wide, flanked by 3-foot asphalt shoulders, beyond which were gravel shoulders of variable width. The general alinement of the highway was fairly good and the sight distance at the particular point exceeded a half mile in each direction. Massachusetts has a 30-mile-per-hour prima facie speed limit, but speeds of 50 miles per hour in daylight and 45 at night are generally not considered unreasonable. The figures analyzed here are based on observation of approximately 1,100 vehicles, a number ample for purposes such as determining average speed or speed distribution, but insufficient to permit a breakdown into many subdivisions. The results must be considered, therefore, as illustrative of procedure only and without significance as to the effect of particular highway conditions. Significant results will be obtained only from a critical analysis of similar records covering longer periods at many locations.

Portions of the three synchronized charts on which the records from this section appear are shown in figure 13. The center chart shows the transverse positions. The lines numbered from 1 to 10 represent the south side of the road, on which eastbound traffic normally moved, and pens 11 to 20 represent the north side, or the lane of westbound traffic. The charts above and below are the speedmeter charts, the upper one corresponding to placement pens 11 to 20 and the lower one to placement pens 1 to 10.

The type of vehicle is manually recorded by means of a telegraph key in series with pen 20 of the placement recorder. If it is evident that pen 20 may be actuated by the vehicle in question, the manual record of the classification is delayed momentarily, but otherwise it

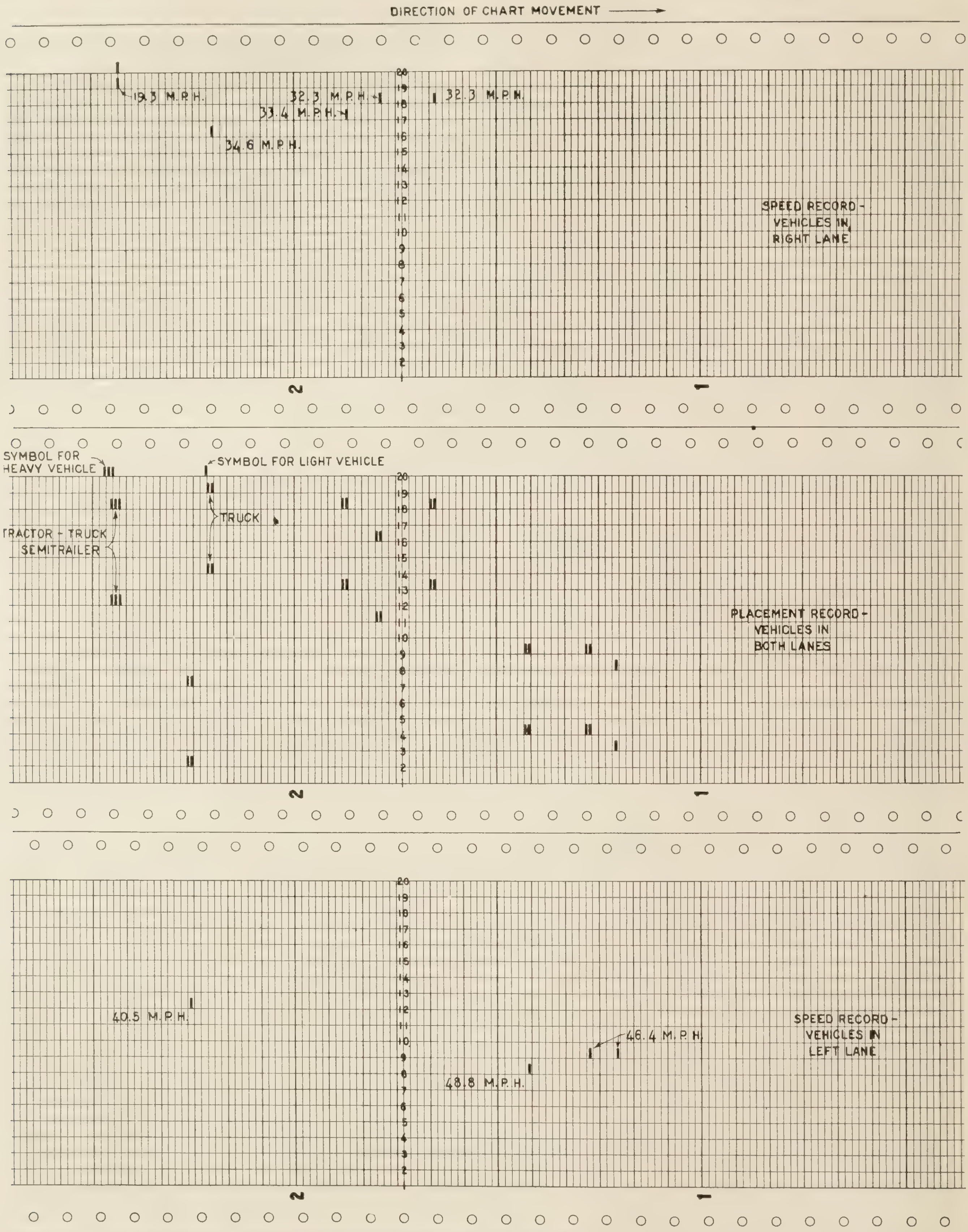

Figure 13.—Portions of Three Synchronized Charts, Showing Samples of Record Obtained on Vehicle Speed and Placement.

appears in line with the wheel records so there is no difficulty in interpretation of the chart records. The longitudinal spacing as well as the transverse position is normally determined from the placement chart, each transverse line representing 1 second in time at the normal chart speed of 6 inches per minute.

The speed of each vehicle can readily be obtained from the upper and lower charts, the mark in each case being in line with the record of the transverse position as shown on the middle chart. The speeds shown beside each mark represent the average of the range of speeds included in the particular speed group. The speed recorded as 34.6 miles per hour, for example, may actually be anywhere between 34 and 35.3 miles per hour.

PLACEMENT DETECTOR GIVES PRECISE RESULTS

Thus for individual vehicles the speeds and speed differences may be slightly in error, but such errors will be compensated for and their effects nullified by the large number of vehicles that will be included in the various speed and speed difference groups.

As mentioned before, the data may be analyzed for purposes of studying both highway capacity and vehicle behavior. Here the primary purpose was to supply data on highway capacity, and the effect of the particular conditions on traffic behavior was secondary. During the hours in which these records were collected, very little change in volume occurred, so no attempt has been made to show here the effect of volume changes on any of the congestion indexes. These indexes have been calculated, however, for later use in studying the effect of various traffic volumes on this section from the complete records.

It was found that the average speed of all vehicles, with the average volume of 375 vehicles per hour, was 41.0 miles per hour; that the average free speed of passenger cars (when no vehicle moving in the same direction was closer than 6 seconds ahead and no vehicle moving in the opposite was closer than 5 seconds ahead or 2½ seconds behind) was 41.6 miles per hour; and the average free speed of trucks was 34.5 miles per hour. The average speed difference was 6.1 miles per hour. It is of interest that these figures all lie within the range for these same indices found on roads of similar alinements in the earlier studies under the method previously used.[4] The close agreement between the average free speed and the average speed of all vehicles, and the relatively high average speed difference show this road to be practically uncongested at this traffic volume.

A further break-down of these vehicle speeds is shown in figure 14. No trucks traveling freely moved faster than 50 miles per hour, and no free-moving passenger car moved faster than 60 miles per hour. The modal averages of these classes of vehicles fell in the 35–39 and 40–44 mile-per-hour groups, respectively. It was of interest that 0.1 percent of all vehicles, traveled more than 70 miles per hour; and that while but 1 percent traveled at 60 miles per hour or faster, all such vehicles were so placed with respect to the other units of the traffic stream that their behavior may have been influenced by the presence of these other vehicles. If so, the influence apparently was not a retarding one. Because the limits of the speed groups as recorded by the speedmeter are not exactly uniform, the speed distributions were first plotted in a cumulative curve from which the number or percentage of vehicles in uniform groups of the desired size were scaled.

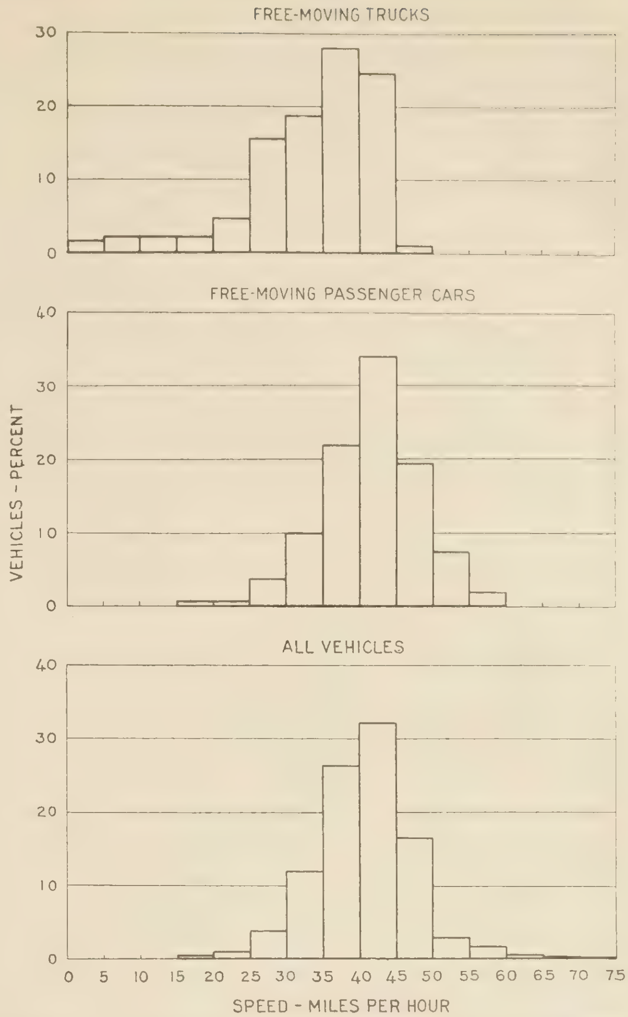

FIGURE 14.—FREQUENCY DISTRIBUTION OF VEHICLE SPEEDS.

The distribution of the time spacings is another index regularly determined in these analyses. These figures are of particular value in coordinating the results of the congestion studies with those obtained in the passing-practice studies. The time spacings of all vehicles traveling in the same direction are plotted as a frequency distribution in figure 15, a further break-down for those below 10 seconds being shown separately.

It is of interest to compare these figures with the general trends of traffic flow discovered in the earlier studies. Almost invariably it was found that between two-thirds and three-fourths of the vehicles traveled at or less than the average spacing. Here 66 percent are found to be traveling at or less than the average of 19.1 seconds. Similarly, previous analyses have shown that approximately half the vehicles travel at half the average spacing or less, and this distribution shows 48 percent not exceeding 9.5 seconds. It was not surprising to find verification of these tendencies. Such close agreement not only confirms the validity of the figures collected under the previous manual methods of recording, but also shows that figures developed from future studies may be combined with those collected in the past work without regard to the method by which any group was obtained. The radical change in the field procedure does

[4] Preliminary Results of Highway Capacity Studies, PUBLIC ROADS, February 1939.

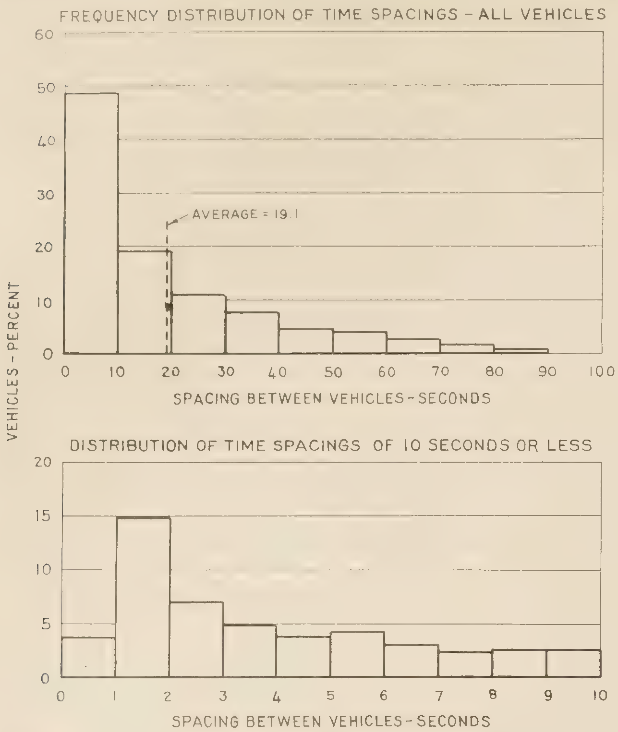

FIGURE 15.—FREQUENCY DISTRIBUTION OF TIME SPACINGS OF VEHICLES.

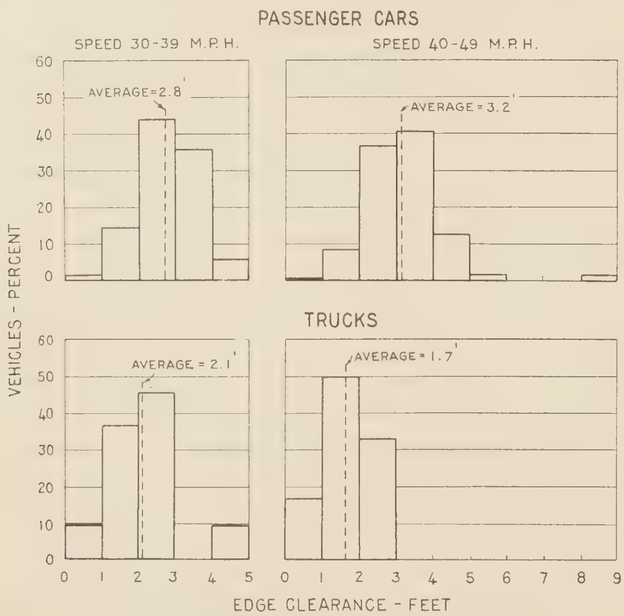

FIGURE 16.—EDGE CLEARANCES OF PASSENGER CARS AND TRUCKS MOVING FREELY.

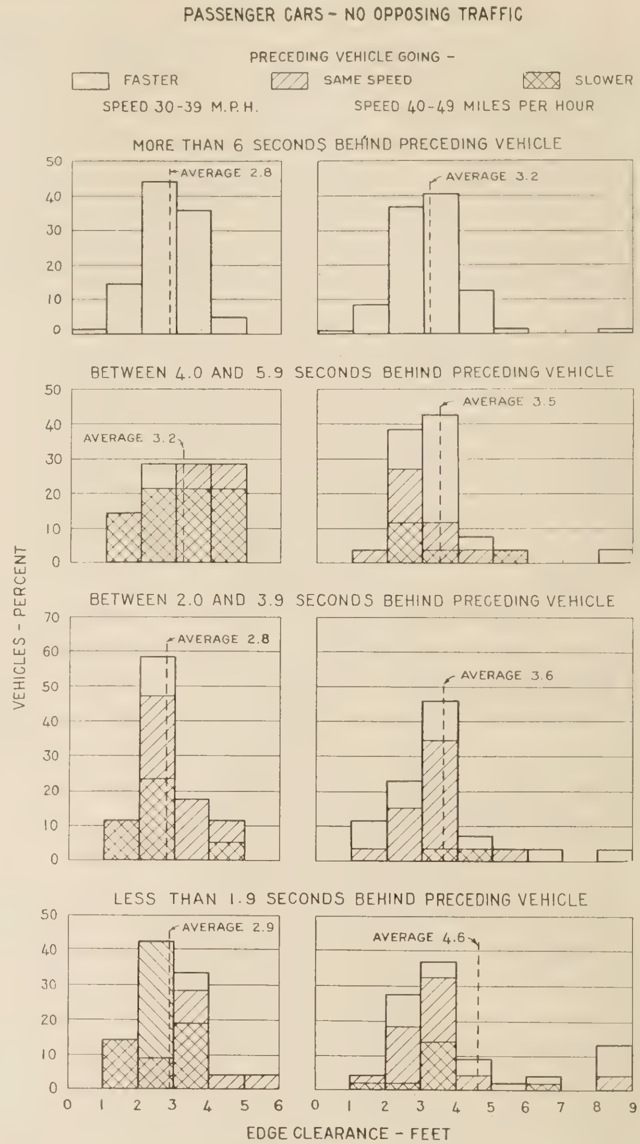

FIGURE 17.—EDGE CLEARANCES OF VEHICLES TRAVELING IN TWO SPEED RANGES AND TRAVELING AT VARIOUS TIME SPACINGS BEHIND PRECEDING VEHICLES.

not, as a consequence, require any change in the treatment of the resulting data.

Many valuable uses will be found for the information on vehicle placement (fig. 16–20). Some of these uses will be shown by the results presented here, but as mentioned before, the significance is severely limited by the size of the sample. First, however, it is of interest to examine the precision of the records. The placement strip will record the position of a wheel of a particular vehicle to the nearest foot only, although if each placement is assumed to be in the center of the segment of the strip actuated, the maximum error in the record of the placement of a particular wheel will be 6 inches. The position of the average vehicle, however, may be found with a high degree of precision. Since the positions of both right and left wheels are recorded, the difference between the positions of the average left and right wheels should equal the tread width of the average vehicle.

In transcribing the field records it is customary, where the record for one side of the vehicle appears on two adjacent segments, to record the wider of the two rather than the average. The field records, therefore, should agree more closely with the rear or wider tread than with the average. The average tread width of all passenger cars was found from the field records to be 4.92 feet. The average rear-tread width of vehicles, as obtained from manufacturers' specifications and weighted approximately in accordance with the occurrence of cars of various makes in the traffic stream, was also found to be 4.92 feet. This absolute agreement between the two is perhaps a coincidence, but it demonstrates that use of the placement strip with 1-foot segments insures satisfactory precision.

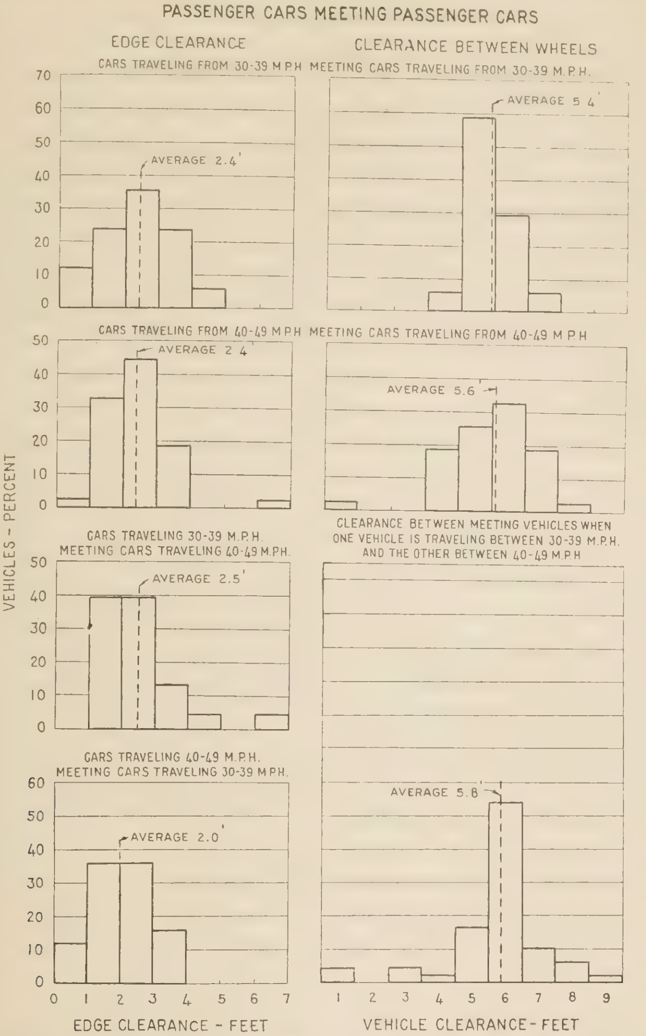

Figure 18.—Edge Clearances and Vehicle Clearances of Passenger Cars Traveling at Various Speeds Meeting Other Passenger Cars Traveling at Various Speeds.

FASTER CARS TRAVEL NEARER CENTER OF ROAD

The transverse position of a vehicle on the road surface is likely to be influenced by a variety of factors both internal and external. The internal factors are largely dependent on the psychological make-up of the driver, and generally are measurable only to the extent that they are reflected in the speed and placement of the vehicle. These psychological factors may be more positively evaluated by subsequent questioning of the drivers in a manner now being explored in cooperative studies with a number of motor-vehicle departments. The external factors may be roughly divided into three broad groups: The physical features at or near the point of study; the presence of vehicles moving in the same direction as the vehicle under consideration; and the presence of vehicles moving in the opposite direction.

Invariably at least two of these factors exert their influence in combination, and the effect of a single factor can never be directly determined. The effect of physical features may be determined with the least complication by selecting for analysis only vehicles that are uninfluenced by other vehicles, although the combined effect of physical features and opposing traffic must also be investigated. In order to include in this category a sufficient number from this particular

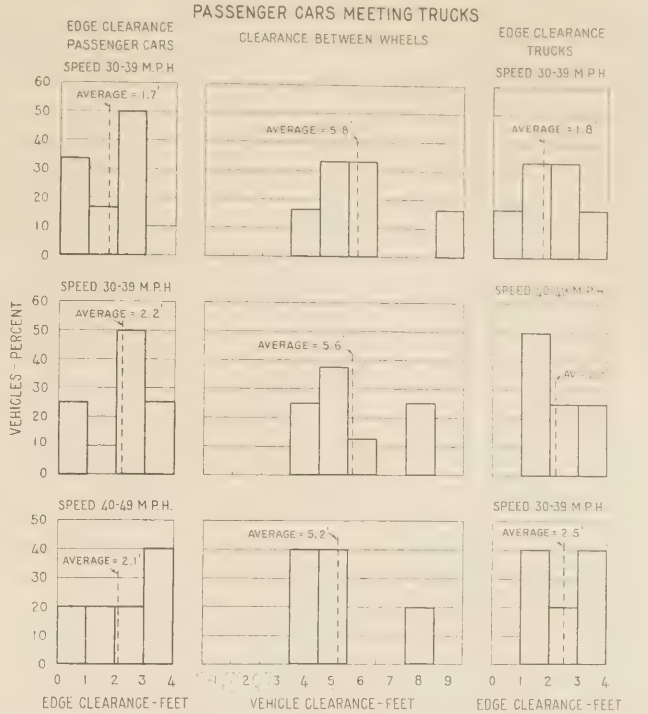

Figure 19.—Edge Clearances and Vehicle Clearances of Passenger Cars Traveling at Various Speeds Meeting Trucks Traveling at Various Speeds.

sample of 1,100 vehicles, free-moving vehicles were considered to be those that had not met another car for 2½ seconds, would not meet another for 5 seconds, and followed a vehicle in the same direction by at least 6 seconds. A vehicle to be met 5 seconds later would be recorded as crossing the placement strip 10 seconds after the car in question, since the meeting would take place midway (in time) between the original positions. Previous studies have shown that drivers may be affected by the presence of a vehicle ahead moving in the same direction when the spacing between them becomes less than 9 seconds. This spacing would be preferable to the 6 seconds used here but would have unduly restricted the size of the sample.

Figure 16 shows the edge clearances of passenger cars and trucks under these conditions. The edge clearance is the distance between the edge of the pavement and the center of the outside tire. Only two speed groups are shown because in other groups the samples were too small. Under the conditions at that particular point, trucks moved closer to the edge of the pavement than did passenger cars, and the faster passenger cars tended to move somewhat nearer the center of the road than did the slower moving cars. Assuming 6½ feet as the width of a passenger car, 98 percent of the passenger cars traveling between 30 and 39 and 94 percent of those traveling between 40 and 49 miles per hour, were entirely in their own lane, and presumably, therefore, would not have collided with properly driven cars in the other direction even without swerving to the right on meeting these other vehicles. Similarly 95 percent of the slower trucks and all of the faster trucks were entirely in their own lane. Some such index as this will permit comparisons between various cross-section designs on a mathematical basis, so that the effectiveness of any combination of roadway features may be exactly evaluated.

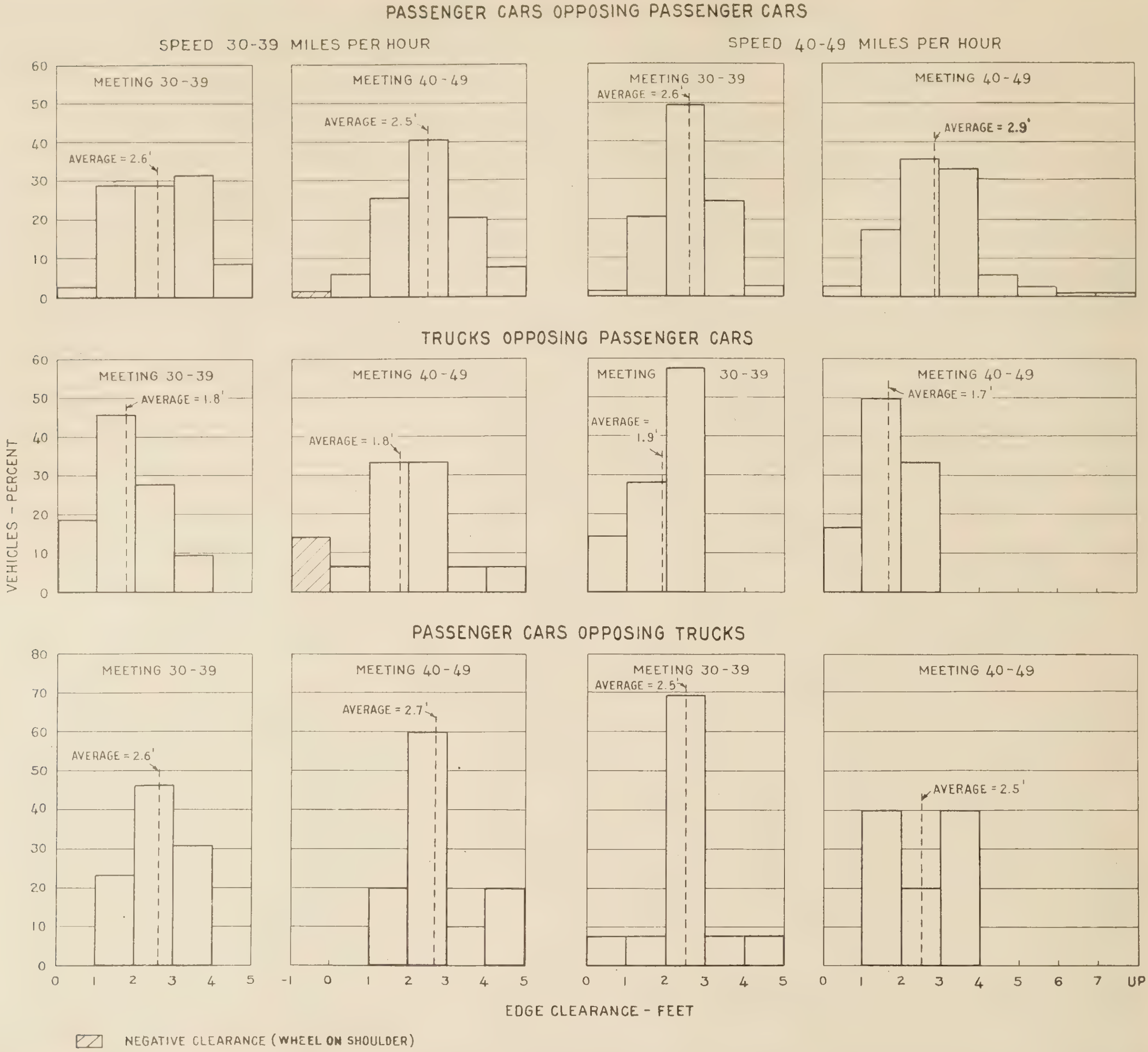

FIGURE 20.—EDGE CLEARANCES OF PASSENGER CARS AND TRUCKS TRAVELING AT VARIOUS SPEEDS MEETING OTHER PASSENGER CARS AND TRUCKS TRAVELING AT VARIOUS SPEEDS.

The presence of vehicles moving just ahead of the one under consideration and in the same direction affects vehicle placement, as shown in figure 17. At the top, for comparative purposes, is shown the transverse distribution of vehicles moving freely (with no vehicle closer than 6 seconds ahead). It is of interest that as the distance between vehicles becomes less, the following vehicles tend to travel nearer the center, possibly to provide better visibility of the road ahead. Following of this tendency by successive vehicles of a group would result in the rearmost vehicles assuming highly hazardous positions.

VEHICLES TRAVEL CLOSER TO EDGE WHEN MEETING ONCOMING TRAFFIC

Figure 18 shows the edge clearances and the distances between passenger cars meeting other passenger cars approximately on the placement strip, and figure 19 shows the same information for passenger cars meeting trucks. In this category are included vehicles crossing the strip within 1 second of one another, which is equivalent to meeting or having met within ½ second. In analysis this number was divided into three groups: Those meeting exactly at the strip; those crossing the strip within ½ second; and those crossing the strip between ½ and 1 second of one another. So little difference was found in the averages for the three classifications that they were grouped together.

This figure shows that the average passenger car on meeting another vehicle moves toward the edge of the pavement somewhat, with the faster vehicles traveling as close to the edge or closer than the slower group. This latter fact is of interest because, as shown by figure 16, the average car of the faster group drove normally at 3.2 feet from the edge as compared to 2.8 feet for the average car in the slower group. Drivers of the faster cars allowed an equal or greater margin of clearance on meeting other cars than did slower drivers, but were required to move laterally a greater distance to do so.

A summation of vehicle clearances aids in obtaining a further indication of the accuracy with which the position of the average vehicle may be determined. The two edge clearances, the tread widths, and the clearance between these meeting vehicles should total the pavement width. In the three classifications shown for passenger cars in figure 18, these distances add to 20.0, 20.2, and 20.1 feet, respectively, the maximum error being 1 percent. Such close agreement is neither expected nor attained in the case of the trucks, however, because of the small sample and the greater variation in truck tread widths.

Since the average passenger car is driven somewhat closer to the center of the road when not opposed by other vehicles, and moves toward the edge on meeting another car, it is of interest to find at what distance from the opposing vehicle this lateral movement is begun. If, for example, the effect of an oncoming vehicle becomes noticeable when that car is 10 seconds away, it is reasonable to assume that the sight distance provided should be the distance traveled in 10 seconds by a vehicle moving at the design speed, in order to permit drivers to perform this lateral transition normally. This distance, which might be termed the "meeting" sight distance can, under certain conditions of alinement and highway usage, be more important from a standpoint of safety than mere stopping sight distance.

Measurement of the lateral movement of a vehicle as it meets another is simply a matter of determining the average transverse positions of vehicles when opposing vehicles are various distances away. Since particular distances between meeting vehicles exist only instantly, rather than continuously as for cars moving at the same speed in the same direction, a very large volume of traffic must be observed to obtain a usable sample of "opposing" spacings. From this particular sample it was impossible to relate the transverse positions to opposing spacings closely enough to determine when the lateral transition began. Figure 20 shows, however, the average positions of vehicles possibly affected by opposing vehicles (i. e., having met another vehicle within 2½ seconds or about to meet one within 5 seconds but not meeting another vehicle within ½ second of crossing the placement strip). As should be expected, the average transverse position of all vehicles about to meet others falls between that for vehicles actually meeting others and vehicles moving freely. It is of interest, however, from a point of view of reliability of the data, that this condition was found invariably in all the classifications of speed and vehicle type.

As stated before, the relationships shown here are intended merely to show the manner in which the transverse placement data may be used. With a greater volume of information, additional relationships may be found, and the analyses greatly refined. With such indexes, established for the more common combinations of standards of surface and shoulder design, and horizontal and vertical alinement, the effectiveness of design features need not be based on opinion and judgment; their actual merit may be definitely evaluated.

FIVE BULLETINS ON BRIDGE FLOOR DESIGN AVAILABLE

Five bulletins on bridge floor design, whose availability for free distribution has previously been announced in PUBLIC ROADS, may still be obtained from the Public Roads Administration. The publications, all University of Illinois Bulletins, are:

- No. 303—Solutions for Certain Rectangular Slabs Continuous Over Flexible Supports.
- No. 304—A Distribution Procedure for the Analysis of Slabs Continuous Over Flexible Beams.
- No. 313—Tests of Plaster-Model Slabs Subjected to Concentrated Loads.
- No. 314—Tests of Reinforced Concrete Slabs Subjected to Concentrated Loads.
- No. 315—Moments in Simple Span Bridge Slabs with Stiffened Edges.

The bulletins are the result of a cooperative investigation by the Engineering Experiment Station of the University of Illinois, the Illinois Division of Highways, and the Public Roads Administration of the Federal Works Agency.

The results of this investigation have direct application to practically all modern highway bridges and to many other structural design problems.

A limited number of these bulletins are still available for free distribution. Requests should be addressed to the Public Roads Administration, Federal Works Agency, Washington, D. C.

STATUS OF FEDERAL-AID HIGHWAY PROJECTS

AS OF MARCH 31, 1940

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 6,590,205	$ 3,189,278	268.7	$ 5,067,117	$ 2,508,413	154.5	$ 1,115,110	$ 554,950	44.8	$ 3,866,067
Arizona	2,042,051	1,447,104	100.1	1,905,859	1,298,649	96.6	55,221	33,200	1.7	1,797,220
Arkansas	5,026,310	3,996,071	226.4	1,616,156	880,291	66.0	1,140,839	564,315	63.3	1,742,802
California	5,552,016	2,977,652	82.1	6,717,815	3,536,324	113.0	1,490,591	742,669	43.2	4,779,982
Colorado	3,860,230	2,132,493	89.3	1,587,936	893,102	44.6	12,516	7,054		3,649,027
Connecticut	871,263	431,585	10.0	1,448,790	722,376	15.0	1,124,229	547,740	9.4	1,475,189
Delaware	844,413	403,702	31.3	1,133,702	565,363	7.2				1,589,560
Florida	3,158,735	1,576,520	33.2	3,693,033	1,842,080	80.3	742,342	369,488	45.0	2,716,363
Georgia	4,295,781	2,032,397	236.0	4,647,443	2,323,722	238.8	3,356,271	1,678,136	112.1	7,178,535
Idaho	2,205,874	1,294,782	113.9	949,011	578,909	67.8	347,504	208,931	26.3	2,245,176
Illinois	8,732,235	4,344,678	195.7	6,103,922	3,049,972	97.2	4,089,850	2,023,425	116.9	4,950,678
Indiana	4,467,296	2,199,299	88.7	4,444,507	2,215,847	95.2	2,578,812	1,289,164	46.2	3,383,791
Iowa	3,897,721	1,823,441	190.7	3,775,417	1,682,388	111.9	1,463,686	691,100	67.2	2,881,769
Kansas	3,514,814	1,709,364	176.4	2,602,274	1,297,426	150.4	4,165,147	2,081,997	244.5	5,784,340
Kentucky	3,352,373	1,664,158	112.3	1,755,563	876,225	31.0	2,357,758	1,178,879	56.0	4,085,122
Louisiana	716,918	355,250	23.9	12,129,245	3,113,488	46.7	1,722,267	843,988	50.7	3,715,371
Maine	2,183,320	1,063,204	52.4	747,557	373,778	16.7	21,640	10,820	.5	1,310,311
Maryland	2,824,344	1,367,116	39.0	1,536,275	759,325	32.4	535,200	257,500	3.4	2,474,054
Massachusetts	3,134,614	1,564,618	25.1	726,621	362,466	5.7	1,734,634	864,024	15.0	3,816,039
Michigan	4,878,603	2,334,336	115.4	3,422,470	1,623,234	113.6	4,186,703	2,093,351	128.3	3,780,133
Minnesota	5,754,882	2,814,684	383.9	3,421,466	1,688,707	161.5	1,675,296	836,990	133.1	5,861,830
Mississippi	5,496,684	1,871,827	256.5	5,469,008	2,350,465	175.6	2,635,700	1,133,500	172.0	2,804,229
Missouri	3,262,387	1,625,018	140.6	4,823,420	2,307,167	122.3	3,931,348	1,520,192	165.8	6,323,727
Montana	3,228,277	1,823,217	189.8	2,327,788	1,319,699	115.9	1,553,848	879,846	156.5	4,976,352
Nebraska	4,717,201	2,314,660	409.0	3,728,606	1,722,813	360.3	3,177,075	1,585,646	430.2	3,756,372
Nevada	1,113,758	943,594	53.6	1,291,654	1,108,687	61.3	163,482	142,523	12.6	1,800,919
New Hampshire	823,550	405,045	27.3	711,819	348,783	15.5	456,360	225,447	8.8	1,309,698
New Jersey	858,420	419,454	7.1	5,562,408	2,780,254	42.2	708,800	354,400	8.0	2,296,092
New Mexico	2,215,677	1,342,931	167.1	1,560,214	972,735	60.6	205,572	125,158	59.0	2,246,136
New York	8,639,476	4,192,678	167.9	12,022,032	5,774,651	168.1	1,314,940	654,970	21.4	5,704,109
North Carolina	5,747,704	2,864,759	353.3	4,420,575	2,210,382	204.5	1,807,150	903,160	93.8	2,800,776
North Dakota	266,609	141,147	41.7	1,307,780	711,478	78.0	3,291,437	1,833,788	309.6	4,414,414
Ohio	5,943,593	2,912,343	84.3	8,710,932	4,332,092	64.9	7,489,851	3,744,740	86.5	6,120,580
Oklahoma	2,524,355	1,335,459	129.4	3,513,155	1,864,539	80.5	2,323,625	1,196,531	105.2	4,755,342
Oregon	2,666,441	1,595,619	108.2	3,449,146	1,931,162	112.8	536,894	313,580	41.9	2,188,239
Pennsylvania	9,656,244	4,762,068	113.7	5,493,574	2,601,802	47.7	5,670,139	2,787,502	68.8	5,884,663
Rhode Island	647,270	318,040	7.8	983,842	490,965	10.2	263,748	131,690	2.5	1,264,218
South Carolina	2,715,688	1,217,808	85.1	1,298,317	606,694	86.5	1,372,409	621,248	89.5	2,855,059
South Dakota	3,427,251	1,891,415	329.1	2,778,040	1,586,760	307.5	1,801,020	994,190	274.7	4,149,123
Tennessee	3,783,232	1,807,048	91.0	3,532,532	1,766,266	62.4	1,584,918	792,459	55.7	4,773,047
Texas	13,156,593	6,466,713	682.3	10,651,731	5,265,137	524.7	2,303,249	1,103,612	132.1	8,597,780
Utah	2,301,982	1,611,553	98.1	792,200	565,065	51.1	158,655	108,560	1.5	1,787,162
Vermont	737,383	348,555	18.4	711,393	355,507	22.7	740,844	366,394	18.1	559,599
Virginia	2,363,545	1,175,262	76.9	2,651,279	1,270,585	60.5	658,946	316,873	17.9	2,680,345
Washington	2,267,884	1,151,202	38.5	3,278,473	1,717,986	27.0	990,224	521,200	30.5	1,698,946
West Virginia	1,956,374	1,033,591	50.1	1,652,026	822,656	48.1	1,225,500	608,655	25.0	2,751,526
Wisconsin	5,171,809	2,539,964	187.9	5,021,815	2,464,880	153.2	55,948	25,805	2.4	4,450,008
Wyoming	1,501,001	917,048	141.3	1,618,252	1,020,311	162.7	391,470	236,637	44.1	1,457,899
District of Columbia	373,200	186,600	2.5	233,724	116,862	2.4	425,236	211,600	3.2	533,063
Hawaii	499,394	232,151	5.1	817,679	408,816	14.5	433,940	215,300	7.7	1,597,995
Puerto Rico	706,072	351,850	14.1	1,306,457	646,785	25.3	56,925	28,180	.2	908,605
TOTALS	176,673,052	90,520,351	6,672.2	171,152,050	83,634,069	5,015.1	81,644,869	40,561,107	3,652.8	170,529,382

STATUS OF FEDERAL-AID SECONDARY OR FEEDER ROAD PROJECTS

AS OF MARCH 31, 1940

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 615,939	$ 301,951	41.9	$ 960,807	$ 379,023	25.1	$ 450,750	$ 224,200	27.7	$ 632,777
Arizona	282,201	201,024	33.4	222,706	123,926	23.1				429,402
Arkansas	949,532	807,994	93.0	130,650	94,073	11.7	44,102	22,051	8.7	348,013
California	821,618	467,084	36.1	422,864	229,524	13.2	445,403	238,232	19.7	997,091
Colorado	900,353	475,952	31.3	247,932	104,109	7.2				278,316
Connecticut	172,310	72,417	2.9	100,760	50,197	.2	210,228	99,380	3.1	234,501
Delaware	80,623	39,067	17.5	69,537	34,768	7.8				309,475
Florida	885,834	438,113	31.3	29,916	14,958	.6	101,240	50,620	1.3	563,391
Georgia	341,690	163,919	44.2	184,992	92,496	16.9	471,231	235,616	44.0	1,278,473
Idaho	458,334	248,575	45.1	128,663	78,481	12.8				293,770
Illinois	1,282,835	625,708	78.8	1,105,035	496,705	62.6	864,950	417,475	33.0	733,174
Indiana	896,572	423,398	77.7	352,270	174,931	23.4	169,070	84,500	13.1	970,530
Iowa	348,453	167,023	128.4	1,141,640	543,885	125.5	1,139,084	536,655	265.9	812,477
Kansas	75,281	37,624	44.4	631,904	315,952	10.9	124,046	62,023	15.0	1,554,612
Kentucky	1,096,826	325,230	71.4	552,881	182,184	37.1	610,401	197,925	64.1	416,283
Louisiana	808,888	390,729	67.2	333,316	166,603	30.3	79,120	39,560	7.8	451,252
Maine	435,011	210,553	25.4	72,824	35,206	3.5	8,300	4,150	.5	142,001
Maryland	281,641	137,157	19.2	117,996	46,998	4.4				474,694
Massachusetts	373,212	185,203	9.2	284,559	140,915	5.9	257,813	127,759	7.1	541,986
Michigan	1,306,129	638,782	113.7	914,039	460,409	45.8	712,925	350,218	57.0	741,020
Minnesota	950,336	467,529	122.3	355,950	146,104	25.8	62,853	31,427	16.5	1,417,984
Mississippi	363,933	181,967	40.7	956,962	466,696	52.1	98,000	48,900	.5	716,477
Missouri	930,960	457,875	139.5	475,232	237,616	36.7	428,992	179,408	67.6	840,278
Montana	817,261	461,241	71.6	293,494	164,033	31.2	430,261	243,181	49.5	767,607
Nebraska	1,024,527	489,997	209.5	416,205	207,944	56.5	337,389	168,695	46.7	453,912
Nevada	164,206	134,299	25.0	197,591	169,920	25.5				228,342
New Hampshire	58,755	29,144	2.3	118,342	55,625	3.2	21,867	10,676	1.0	197,644
New Jersey	332,799	163,171	12.1	306,190	153,095	12.3	310,690	155,345	6.0	522,939
New Mexico	470,132	287,240	42.1	266,287	166,062	13.8	101,564	63,386	13.1	262,435
New York	1,820,821	879,099	91.3	1,613,175	775,643	44.8	537,841	203,721	12.7	797,640
North Carolina	1,069,398	531,728	106.2	620,243	312,733	54.6	338,390	159,915	28.2	394,504
North Dakota	115,841	61,370	8.3	62,121	34,895		150,963	80,915	3.8	1,012,290
Ohio	697,494	347,437	41.8	907,770	460,660	38.6	2,062,400	980,057	64.0	1,044,378
Oklahoma	260,138	133,815	10.5	744,506	395,457	51.3	202,390	107,007	22.1	1,039,633
Oregon	614,073	347,752	67.6	304,094	164,557	35.5	167,895	101,020	23.9	371,626
Pennsylvania	2,044,841	991,595	117.1	1,253,808	620,799	43.1	950,637	474,556	25.2	429,527
Rhode Island	93,827	46,890	2.2	186,882	93,441	2.0	43,173	21,560	1.6	95,049
South Carolina	578,846	234,056	56.9	297,040	112,595	25.9	358,820	134,229	35.1	307,605
South Dakota	16,229	8,937	4.1	14,680	9,712					1,280,913
Tennessee	818,717	351,682	31.7	146,416	73,208	.7	175,069	87,534	10.9	986,082
Texas	2,442,661	1,203,995	269.0	1,187,653	583,568	140.2	307,076	147,210	55.3	1,322,941
Utah	229,586	126,765	38.5	121,120	76,528	8.3				297,598
Vermont	138,763	63,954	5.6	164,292	50,336	6.3	167,400	52,029	5.8	83,270
Virginia	649,933	315,482	65.5	465,030	206,433	18.4	99,000	49,500	13.5	383,337
Washington	585,503	303,938	43.1	281,527	147,657	16.9	138,883	73,500	15.7	378,872
West Virginia	145,150	72,575	8.3	331,265	165,632	18.0	139,458	69,204	8.0	447,839
Wisconsin	883,504	439,012	34.5	321,053	160,190	4.7	379,319	179,040	4.4	833,468
Wyoming	470,702	286,620	26.0	329,482	195,846	23.5	53,943	34,052	15.5	189,322
District of Columbia	98,700	49,350	1.0	41,692	20,346	.5				76,554
Hawaii	193,033	96,211	6.2	273,208	137,108	8.6				159,806
Puerto Rico	30,220	14,440	2.2	244,134	119,025	12.9	55,188	27,140	2.1	109,023
TOTALS	31,524,171	15,936,669	2,714.8	21,302,735	10,448,807	1,279.9	13,808,124	6,573,571	1,116.7	29,652,133

U. S. GOVERNMENT PRINTING OFFICE: 1940

PUBLICATIONS of the PUBLIC ROADS ADMINISTRATION

Any of the following publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. As his office is not connected with the Agency and as the Agency does not sell publications, please send no remittance to the Federal Works Agency.

ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1931. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1933. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1934. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1935. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1936. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1937. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1938. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1939. 10 cents.

HOUSE DOCUMENT NO. 462

Part 1 . . . Nonuniformity of State Motor-Vehicle Traffic Laws. 15 cents.

Part 2 . . . Skilled Investigation at the Scene of the Accident Needed to Develop Causes. 10 cents.

Part 3 . . . Inadequacy of State Motor-Vehicle Accident Reporting. 10 cents.

Part 4 . . . Official Inspection of Vehicles. 10 cents.

Part 5 . . . Case Histories of Fatal Highway Accidents. 10 cents.

Part 6 . . . The Accident-Prone Driver. 10 cents.

MISCELLANEOUS PUBLICATIONS

No. 76MP . . The Results of Physical Tests of Road-Building Rock. 25 cents.

No. 191MP. . Roadside Improvement. 10 cents.

No. 272MP. . Construction of Private Driveways. 10 cents.

No. 279MP. . Bibliography on Highway Lighting. 5 cents.

Highway Accidents. 10 cents.

The Taxation of Motor Vehicles in 1932. 35 cents.

Guides to Traffic Safety. 10 cents.

An Economic and Statistical Analysis of Highway-Construction Expenditures. 15 cents.

Highway Bond Calculations. 10 cents.

Transition Curves for Highways. 60 cents.

Highways of History. 25 cents.

DEPARTMENT BULLETINS

No. 1279D . . Rural Highway Mileage, Income, and Expenditures, 1921 and 1922. 15 cents.

No. 1486D . . Highway Bridge Location. 15 cents.

TECHNICAL BULLETINS

No. 55T . . . Highway Bridge Surveys. 20 cents.

No. 265T. . . Electrical Equipment on Movable Bridges. 35 cents.

Single copies of the following publications may be obtained from the Public Roads Administration upon request. They cannot be purchased from the Superintendent of Documents.

MISCELLANEOUS PUBLICATIONS

No. 296MP. . Bibliography on Highway Safety.

House Document No. 272 . . . Toll Roads and Free Roads.

Indexes to PUBLIC ROADS, volumes 6–8 and 10–19, inclusive.

SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y . . Road Work on Farm Outlets Needs Skill and Right Equipment.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio (1927).

Report of a Survey of Transportation on the State Highways of Vermont (1927).

Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio (1928).

Report of a Survey of Transportation on the State Highways of Pennsylvania (1928).

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

UNIFORM VEHICLE CODE

Act I.—Uniform Motor Vehicle Administration, Registration, Certificate of Title, and Antitheft Act.

Act II.—Uniform Motor Vehicle Operators' and Chauffeurs' License Act.

Act III.—Uniform Motor Vehicle Civil Liability Act.

Act IV.—Uniform Motor Vehicle Safety Responsibility Act.

Act V.—Uniform Act Regulating Traffic on Highways.

Model Traffic Ordinances.

A complete list of the publications of the Public Roads Administration, classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to Public Roads Administration, Willard Bldg., Washington, D. C.

STATUS OF FEDERAL-AID GRADE CROSSING PROJECTS

AS OF MARCH 31, 1940

STATE	COMPLETED DURING CURRENT FISCAL YEAR					UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
			NUMBER					NUMBER					NUMBER			
	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	
Alabama	$ 950,297	$ 946,632	10	2		$ 349,007	$ 348,924	8			$ 513,500	$ 513,500	2		5	$ 884,449
Arizona						518,060	515,813	4								400,746
Arkansas	184,063	184,017	3			672,928	666,423	3		3	332,008	330,926	4	1	8	807,458
California	1,156,384	1,151,614	8		1	1,331,046	1,164,844	8			55,247	54,747	1		6	1,885,803
Colorado	650,310	638,128	5		21	287,948	287,948	1		4	2,250	2,250			1	901,446
Connecticut	26,225	12,665				175,125	169,677		1	7	499,382	494,023	5			583,749
Delaware	7,839	7,839	2								96,433	96,433			16	568,269
Florida	428,094	428,094	2			196,653	192,154	2			23,903	23,903			6	1,438,727
Georgia	205,441	202,084	5		2	534,133	534,133	9	3		468,037	468,037	4	4	20	2,394,875
Idaho	204,578	172,785	3			215,380	214,413	2			135,426	105,800	2		3	499,709
Illinois	2,606,975	2,544,487	17	4	49	1,876,839	1,743,987	7		28	576,809	462,420	4	1	85	2,496,711
Indiana	770,618	770,618	3	1	61	706,108	706,108	3	2	51	193,324	193,324	1		58	1,390,943
Iowa	1,029,515	943,100	13		156	257,418	243,500	2		37	412,827	333,200	2		79	1,403,745
Kansas	934,280	931,180	11		8	658,242	658,242	8		1	454,856	454,856	5	2	11	1,197,144
Kentucky	594,500	589,647	8	4	5	820,701	820,702	7		1	240,150	240,150	4		21	813,688
Louisiana	493,976	493,958	4			460,321	406,826	5			627,885	570,153	11			789,393
Maine	336,835	334,299	3	2		209,733	209,733	2	1		13,768	13,768			5	416,551
Maryland	94,896	85,789	1		3	454,009	454,009	3		2	218,600	145,807		1	10	841,925
Massachusetts	400,519	399,288	2	2		122,047	122,014	2								2,335,881
Michigan	854,794	844,327	6	2	36	1,166,142	1,166,142	5	3	4	491,859	491,859	4		12	1,493,601
Minnesota	503,520	477,825	4	4	14	1,433,340	1,432,246	10	2	3	230,130	230,130	1	1	2	1,572,650
Mississippi	246,300	246,300	6			590,973	590,973	5	1		45,200	45,200	1			1,121,139
Missouri	402,019	400,714	2	1		1,419,062	1,419,062	9	2		861,759	584,775	1	3	1	1,795,880
Montana	850,426	850,426	9			217,073	101,991	3			92,599	90,817	2		4	609,806
Nebraska	704,212	703,613	19		30	861,548	861,548	7	2	10	79,004	79,004	1		14	820,634
Nevada	209,333	207,536		4	11	10,353	10,353			2						251,043
New Hampshire	102,433	101,921	7		1	103,328	103,292	3			77,921	77,921	1			392,776
New Jersey	262,682	262,682	1	1	1	743,959	743,959	3	2							1,755,390
New Mexico	72,824	71,821	2		1	188,425	188,425	2			138,907	138,907	1		4	620,095
New York	1,906,664	1,872,132	5	8		2,362,773	2,324,513	8	9		938,418	893,894	4	5	8	3,914,235
North Carolina	1,214,339	1,177,921	6	5	38	828,323	828,323	11	1	19	154,030	154,030	1	1	10	1,142,692
North Dakota	529,910	481,298	7	1		391,290	391,290	5			151,060	151,060	2		19	781,057
Ohio	543,740	528,740	8	1	3	1,504,853	1,433,901	8	2	1	977,340	977,340	5	1	1	3,372,589
Oklahoma	371,620	370,352	5		46	256,085	255,185	3	1	2	633,091	633,091	9		31	2,102,263
Oregon	173,428	171,720	2			318,721	218,374	3								568,943
Pennsylvania	1,480,102	1,268,203	2	2	1	1,167,064	1,167,064	10	2	1	350,000	350,000	1			5,568,697
Rhode Island	446,089	445,450	1	3		7,406	7,406									284,644
South Carolina	482,827	449,677	7	4	7	454,983	454,983	4	5		140,775	140,775	1	1	26	1,075,529
South Dakota	329,428	329,428	3	2	17	79,127	79,127	1	1		106,640	106,640	2		3	1,338,497
Tennessee	283,398	283,398		2	5	590,551	590,551	3	2							1,898,536
Texas	2,049,324	2,028,265	19	3	12	2,169,663	2,097,840	18		8	19,050	19,050			7	2,883,692
Utah	315,211	315,050	3		110	74,108	74,108			24	32,650	32,650			11	368,855
Vermont	32,135	27,295			7	206,402	206,402		2		2,969	2,969			1	260,937
Virginia	690,071	597,171	7	3	18	215,447	214,577	4			142,427	141,828	1	2	5	1,276,463
Washington	338,538	337,062	3	1	12	223,296	223,296	3	2		280,077	280,077	3	1	3	526,259
West Virginia	291,281	275,521	5		1	99,270	99,270	4			112,100	112,100	1		3	1,258,032
Wisconsin	905,123	885,062	9		10	828,576	782,479	7	2	1	468,167	439,834	2	1	11	1,385,774
Wyoming	136,007	135,851	1	1	8						85,910	85,910	1			632,365
District of Columbia						359,912	326,368	1								200,203
Hawaii	162,720	160,090	2	1		30,682	30,682	2			236,535	236,525	2		1	261,573
Puerto Rico	49,040	48,840	1			365,872	363,870	8			252,884	248,576	2			381,747
TOTALS	28,014,883	27,191,915	252	64	695	29,114,305	28,247,050	226	48	209	11,965,907	11,248,259	94	25	511	63,967,808